# MIT Technology Review

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# When will devices have intuition?

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# From the Editor

**Privacy is good. Without privacy nothing** that we care about can thrive: neither marriages, nor art, nor science, nor technology, nor contracts, nor democracy, nor anything much at all.

Technologies that protect our privacy, such as encryption, are therefore useful. In general, we want as much secrecy as we can bear, and as more of our lives are conducted using smartphones and we store more information in a digital cloud, or contemplate being ferried by autonomous vehicles or living in smart houses, we look to technology companies, such as Apple, to provide us with a reasonable degree of privacy.

But should technology companies create black boxes, whose encryption is so strong that they cannot be unlocked without their users' consent, a lucky guess, or treachery, even if law enforcement has a legitimate interest in seeing the boxes' contents?

In "What If Apple Is Wrong?" on page 74, Brian Bergstein, *MIT Technology Review's* executive editor, describes crimes where being able to unlock iPhones would identify a murderer or help free an innocent person and asks, "Are we certain we want to eliminate an important source of evidence that helps not only cops and prosecutors but also judges, juries, and defense attorneys arrive at the truth?" That "essential question" was mostly overlooked during the confrontation between the FBI and Apple, when the company refused to disassemble the locks on an iPhone that Syed Rizwan Farook had used before he and his wife killed 14 people in San Bernardino, California.

President Obama, speaking at the South by Southwest conference in March, grasped that essential question, lecturing the audience of technologists, many of whom were fans of strong encryption: "Dangers are real. Maintaining law and order and a civilized society is important ... And so I would just caution against taking an absolutist perspective ... If in fact you can't crack [phones] at all, if the government can't get in, then everybody is walking around with a Swiss bank account in their pocket. There has to be some concession to the need to be able to get into that information somehow."

Privacy rights cannot be guaranteed by technologies, which are contingent on the willingness of their manufacturers to create them, or by the continued existence of those companies. But a more limited privacy than technologists promise is guaranteed by the Constitution of the United States, which (as the president reminded us) has always allowed that police can enter one's house and rifle through one's personal effects, so long as they have a warrant issued by a judge. If it follows that allowing phones to be subject to search warrants makes them more vulnerable to hackers, then that is a trade-off we must accept in the real, fallen world of murders and human trafficking, so long as the increase in vulnerability is in fact small.

When Tim Cook, Apple's CEO, vows to continue to increase the strength of the encryption on his company's products, he is proposing to make commonplace something that has hitherto been rare: zones of privacy that are potentially impenetrable. But no one made Tim Cook king. At SXSW, President Obama warned against "fetishizing our phones above every other value," and he insisted that "the notion that somehow our data is different and can be walled off from ... other trade-offs we make is incorrect."

No right is absolute, because all rights butt up against other rights, with their own strong claims. In open, democratic societies, we are committed to continually negotiating rival claims, as values change and technologies evolve.

But write and tell me what you think at jason.pontin@technologyreview.com.

GUIDO VITTI

REPUBLIC OF TURKEY PRIME MINISTRY
INVESTMENT SUPPORT AND
PROMOTION AGENCY

# R&D + Innovation + Entrepreneurs = Turkey's Technology Ecosystem

Turkey is a land of vast opportunity. A series of government reforms designed to nurture a tech-driven economy has tripled GDP over the past decade and created a dynamic R&D community that is transforming Turkey into a flourishing hub for promising technologies. Private-sector R&D centers are accelerating and excelling, thanks to grant programs and tax deductions for entrepreneurs engaging in leading-edge projects.

**Incentives will enable Turkey's entrepreneurial community to realize its vast potential by 2023, when the Turkish Republic celebrates its 100th anniversary.**

The Turkish government is continually amending and boosting incentives related to the design and development of products and services with high added value. The latest step: a new R&D reform package. Unveiled in January by Prime Minister Ahmet Davutoğlu, this investment plan will increase the competitiveness of vital industries, strengthen university/industry cooperation, and boost overall R&D spending.

**Turkish Technology on Track**

Turkey's R&D, innovation, and entrepreneurship ecosystem is currently on track to meet two key targets by 2023:

- Triple gross expenditure on R&D (GERD) to 3 percent of gross domestic product.
- Increase the number of researchers to 300,000 full-time equivalents, up from 115,000 today.

The private sector is expected to lead the way in hitting these targets by raising its GERD to 2 percent of GDP and its share of researchers to 180,000.

Key elements include:

- New design centers that will benefit from the same level of incentives as R&D centers.
- Support for design-related activities in technology development zones (TDZs).
- Specialized TDZs for priority and strategic sectors (information and communication technology, health care, biotechnology, nanotechnology, defense, and aerospace, among others) to form focused R&D organizations.
- Tax deductions for companies engaged in R&D and design, including small and midsize enterprises that contract such services to outside parties.
- Tax deductions and grants for pre-competition cooperation projects to encourage joint projects.
- Tax deductions for companies that provide venture capital for startups established under the Techno-Initiative Capital Support Program in TDZs.
- Customs-duty exemptions for materials from abroad used in R&D, innovation, and design projects.
- Creation of a standardization and authorization system for software projects.

Turkey's young, well-educated, and tech-savvy population is at the core of its entrepreneurial prowess. These incentives will support this innovative community in realizing its vast potential by 2023, when the Turkish Republic celebrates its 100th anniversary.

**Private-sector R&D centers are accelerating and excelling, thanks to grant programs and tax deductions for entrepreneurs engaging in leading-edge projects.**

**For more information, visit: invest.gov.tr**

# Contents

## Front



China's automation ambitions, p. 44

## May/June 2016



## Back

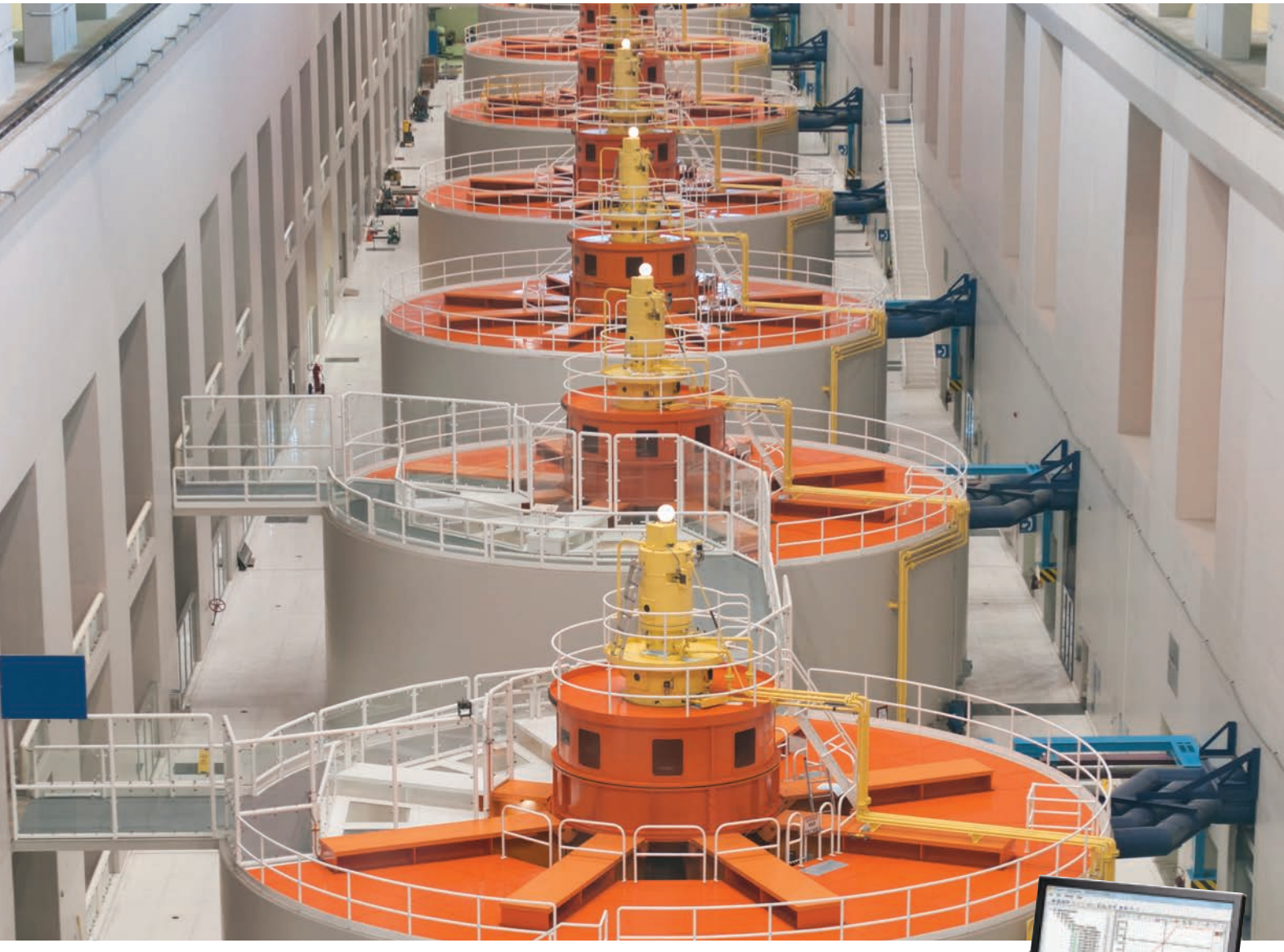


**ON THE COVER:**

*Photograph by Jonno Rattman*

DANIELE MATTIOLI

# Who will prevent downtime and equipment failure?



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## Five Most Popular Stories

*MIT Technology Review*
Volume 119, Number 2


**1**

### 10 Breakthrough Technologies: Robots That Teach Each Other

We're moving closer and closer to the point where everything is done by robots. So everything will be cheaper, but no one will have paychecks.

—**Sydney Otterbein**

**2**

### Should Silicon Valley Go to War?

We have a long history of enlisting our corporations to join war efforts. Right now there are thousands of defense contractors working in the digital realm. Is using a consumer digital company to root out the enemy any different from having GM build tanks or Ford build airplanes? —**markduran**

What do you mean "should" they? They already are at war. Silicon Valley seems to be a spinoff from the military-industrial complex, though that might come as a shock to some.

—**Hendrik van Leeuwen**

**3**

### 10 Breakthrough Technologies: Gene Editing in Plants

People need to be fed. So if to feed 10+ billion people we have to develop an efficient way of optimizing crops' genetics, so be it.

—**Mourad Sabri**

Feeding the world is not a question of increasing production, it is a matter of increasing distribution. It's a political issue, not an agricultural one.

—**Leif Olson**

You can edit genes until you're blue in the face. It will always remain futile and in the long term worthless until you learn how the microbiome of soil functions and can adjust it naturally. —**John Roberts**

**4**

### When Biology Meets Ideology

It just goes to show that knowledge of the natural world over time tends to undermine authority in philosophy and politics. Only in a totalitarian system could obscurantism and superstition become official truth. —**eugah**

In the future we should have machine intelligence capable of processing more data on any subject in history—this could provide a more accurate interpretation of history.

—**Jacob Plashko**

**5**

### 10 Breakthrough Technologies: Power from the Air

I would suggest that nobody depend on this being very useful for a very long time, if ever.

—**Henry Cave Devine**

Well, Nikola Tesla ran successful experiments with wireless transfer of energy around 100 years ago. It's about time modern science took baby steps in that direction.

—**Alan Seletkovic**

### The Addictive Experience of Driving on Autopilot

Regarding Tesla Autopilot ("10 Breakthrough Technologies," March/April 2016): my wife and I own two Teslas—an older 2013 Model S with no Autopilot and a 2015 S with Autopilot. Unfortunately for me, the newer car is my wife's daily commuter. I have driven it on several trips from Pennsylvania to Virginia (where I used the Autopilot perhaps 95 percent of the time) as well as on numerous local trips, and I can attest that the feature is very addicting. When I'm back on my 2013 non-Autopilot car, I do feel that I'm driving an "older" car, miss the Autopilot very much, and feel a bit more stressed driving without it.

A few observations: The Autopilot is very intuitive. In 30 minutes or less you start to feel comfortable with the feature. The car seems to learn by experience, so that performance improves with time. It's especially useful in stop-and-go traffic, smoothly accelerating to keep up with traffic and coming to a complete stop when needed, resuming speed to keep up with moving traffic again. The self-parking features, both parallel and perpendicular, are simply amazing. The car can park itself in spots I would never attempt on my own.

Even if there are no further advances in the technology, this first step is a big one, and already very useful. **—jillyalex**

### Don't Give SolarCity Too Much Credit for Taking a "Risk"

In "10 Breakthrough Technologies: SolarCity's Gigafactory" (March/April 2016), Richard Martin writes: "It is, however, SolarCity's willingness to take on such risks that makes the Buffalo facility so ambitious." But it's actually New York taxpayers who are paying for this. How exactly is that risky to the business? Haven't we learned from other, similar federal failures? Even the highly touted German solar industry is under fire, with the government in Berlin acknowledging that taxpayers have no more appetite for the subsidies. **—Lee Wick**

### Do We Know What We're Doing with Gene Editing?

With reference to "10 Breakthrough Technologies: Precise Gene Editing in Plants" (March/April 2016), it's worth asking: have we really understood the long-term impact of changing one gene on one organism? On other organisms in life's web? How about changing hundreds of genes and shipping them broadly? Do we really know how they express themselves and interact? Are we sure that business interests haven't influenced the thinking? And when does human gene meddling end? **—bruceck**

### Artificial Intelligence Won't Have a Conscience Unless We Give It One

I think we should be very worried about artificial intelligence ("Will Machines Eliminate Us?" March/April 2016). An AI would not have human capabilities like compassion and conscience when making decisions unless we build them into it from the beginning. But will every AI developer do that? **—JacobsenMic**

### How Working on the Weekend Became the Norm

As Julie Morgenstern points out ("E-mail's Not the Issue," March/April 2016), e-mail might be a great tool, but it's sapping our productivity and creativity. Leaders need to create a culture that values and protects employees' quiet time to think and get things done. So many people I know say they can't get any work done at work, so they end up working when they get home, and that work bleeds into weekends. E-mail is a big part of the problem, but so is corporate culture and management expectations. **—lisaleefreeman**

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# Views

Susan Hennessey

Shaun Rein

Zach Adelman

COMPUTING

## Winner Take Nothing

The FBI got into an iPhone in a terrorism case, but that didn't really solve anything.

**The FBI has hacked into an iPhone and** dropped its case against Apple, but that does nothing to resolve the larger issues (see "What If Apple Is Wrong?" page 74). Device security will get more sophisticated, placing more data beyond the reach of search warrants. And law enforcement will still face the "going dark" problem—when it has the legal right to view communications but lacks the technical ability to do so.

More than four decades ago, economist Arthur Okun penned his influential tome *Equality and Efficiency: The Big Tradeoff*. The title refers to the way we find balance by alternately favoring, say, the security of our information systems and the effectiveness of law enforcement, sacrificing the ideal of either in an effort to preserve a bit of both.

Apple vs. the FBI presents just such a trade-off. We can promote maximally secure information technology systems and pay some real costs in terms of how effective law enforcement can be. Or we can promote maximally efficient law enforcement and pay some real costs in the potential compromise to our information systems. Neither scenario offers the ideal.

Making trade-offs is crucial. The future won't be won by ideologues who speak in absolutes but by reasonable people willing to confront the downsides of every path. Such matters won't be settled by any individual court case or piece of legislation. Instead, the issues will be continually challenged and refined over time.

Despite the prevailing winner-take-all rhetoric, it's possible to create meaningful legislation that's flexible. Rather than broad edicts about what must be accessible to law enforcement, Congress can set forth the factors that courts should consider when determining whether a company should be compelled to provide a particular type of assistance and expressly limit what the government may request.

Any legislation would provide a mere baseline. The courts have the power to make fact-specific determinations as technology evolves—for example, relying on expert testimony to determine the feasibility of outside methods or the obligations to exhaust alternatives. The courts will also determine matters related to the overall equilibrium, such as whether individuals, under the Fifth Amendment, can be compelled to input a password or decrypt data.

The proliferation of new technologies will continue to reset the balance. Law enforcement may discover new tools, as has happened in California, and the emergent Internet of things may compensate for information loss. The balance will be further refined through the coöperation of private companies dealing with the expectations of customers—who will somehow want the companies to both help law enforcement and protect their data.

Any choice we make poses risks. But the future won't be shaped by any one big trade-off—only many small ones.

*Susan Hennessey is a fellow in national security in governance studies at the Brookings Institution.*

ROBOTICS

## Doing the Dirty Work

Young people in China don't want factory jobs. So robots do the work instead.

**Many people still assume that as the** world's most populous nation, China has a limitless supply of cheap labor. While that was true in the 1990s, the reality is that the manufacturing sector faces a

ANDY FRIEDMAN

challenge people thought impossible just a few years ago: a dearth of workers.

Younger Chinese born in the 1990s are no longer willing to toil in factories for very low wages, and the country overall faces an aging population because of the one-child policy. Its young people have white-collar dreams and prefer to work in service sectors. They want to buy iPhones rather than make them.

In the 1990s, service accounted for 50 percent of China's economy. It now accounts for 68 percent. Chinese workers are now a third as productive as their counterparts in America or Germany. My firm, the China Market Research Group, estimates that it's now only about 20 percent cheaper to manufacture in China than in the U.S. Some Chinese companies, like the construction manufacturer SANY, are even setting up manufacturing operations in the United States.

This is why manufacturers have turned their focus to automation (see "The People's Robots," page 44), which is one of the fastest-growing sectors in the country, with a growth rate of 59 percent last year. China is now the world's largest user of industrial robots.

Foxconn, the maker of iPhones and other gadgets, operates factory-cities that employ upward of 350,000 people, but it is replacing people with robots because it can no longer find the workers it needs. It's now easier and cheaper for Foxconn to automate than it is to train workers. After 2010, when 14 Foxconn workers committed suicide, the company started an initiative to use robots in its factories' "3D" positions—dirty, dangerous, and dull. It hopes to reach 30 percent automation by 2020 by installing more than a million robots on its production lines.

Chinese real estate developer Vanke has invested $20 million to establish a robotics R&D center to reduce its reliance on human labor. Hyundai and its partner Beijing Motors recently completed a factory that will produce over a million cars a year, mostly using robotic assembly. Even restaurants in Shanghai are using robots to make udon noodles because they can't find enough cooks.

China won't lose its manufacturing dominance anytime soon. It has advantages in scale and logistical capabilities. But it will become the leading hub for innovation in manufacturing by adopting and creating robotics faster than any other nation.

*Shaun Rein is the author of the best-selling book* The End of Cheap China.

BIOMEDICINE

## Let's Kill the Mosquito

We should use new genetic technology to eradicate the disease-causing bug.

**Humans have driven species to extinc**tion through our hunger, ignorance, desire for economic growth, and indifference. Will one species of insect be the first we eliminate for humanitarian reasons?

The insect is *Aedes aegypti,* commonly known as the yellow fever mosquito and, in recent years, as the dengue mosquito for the way it spreads a hemorrhagic disease that disproportionately affects small children and has high public health costs. Now it's suspected of transmitting the Zika virus, linked to microcephaly in newborns.

Once confined to a small region of sub-Saharan Africa, *Aedes aegypti* has invaded the Americas, Asia, the South Pacific, and Australia within the last few hundred years. While people have long called for the mosquito's eradication, the recent development of "gene drive" technology makes this a real possibility (see "The Extinction Invention," page 54). Unlike an ordinary gene, which is passed on to just half of all offspring, a gene-drive construct could be passed on to virtually all offspring. It can be used to spread genes that destroy female mosquito chromosomes, prevent female mosquitoes from flying, or determine whether a mosquito becomes a male.

By releasing a small number of gene-drive mosquitoes, we could reduce each generation of wild females until they disappeared completely. Within weeks, all the males would die out, too, along with the genetic modification that caused their disappearance. Though there are certainly technical and regulatory milestones ahead, what would happen if it worked? First off, it would save more than 20,000 lives per year from dengue alone and prevent millions of cases of illness. In addition to stopping dengue, Zika, and other viruses such as chikungunya, eliminating this mosquito would prevent the spread of other obscure viruses that have been catalogued and may be waiting their turn to cause the next epidemic.

What about the ecosystem? As a species, we are guilty of repeatedly taking actions without thinking about the effects on the environment. Considered in isolation, anything that damages "the ecosystem" sounds bad. But this ecosystem is cans, buckets, pots, trash, tires, and whatever else is lying around collecting rainwater. *Aedes aegypti* doesn't breed in ponds, marshes, swamps, or wetlands, and thus there are no frogs and no fish to eat these mosquitoes—one reason they've done so well as a species. Currently, our ability to control dengue (and now Zika) is dependent on our ability to remove the places where *Aedes aegypti* lives and breeds. If we are willing to destroy an entire ecosystem (that is, clean up garbage and screen over water storage containers), why not eliminate just this mosquito instead?

*Zach Adelman is an associate professor of entomology at the Fralin Life Science Institute at Virginia Tech.*

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# Upfront

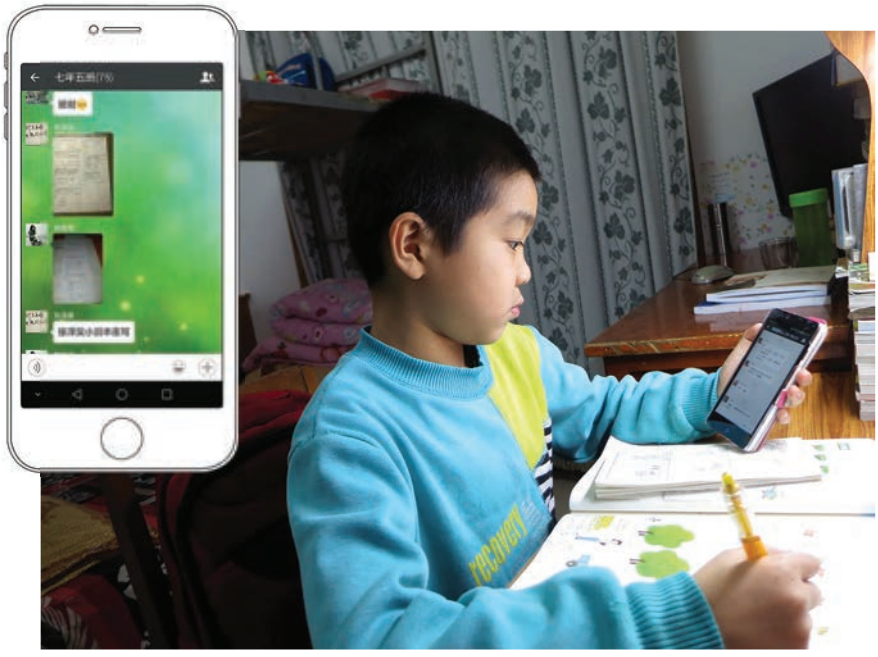
MARINA MUUN

## WeChat Transforms China's School Days

How teachers, parents, and students in some schools in China are using the messaging app to perpetuate round-the-clock pressure.

**On a recent Thursday evening, Zhang** Zehao, a seventh grader in Tianjin, China, braced himself for extra math assignments posted by his teacher on WeChat, a messaging app. At 7 P.M., his mother received a picture on her phone: a piece of paper with three handwritten geometry problems concerning parallel lines. He

# Upfront



*Li Guibin checks WeChat to see what his math homework assignments are.*

didn't receive any other assignments that evening; after all, it was only the fourth day of the spring semester.

Since Tencent launched WeChat in 2011, the app has come to pervade Chinese life. The company reported that it had 650 million monthly active users as of the end of last September. In a society that places paramount importance on academic success, WeChat has quickly become intertwined with education, tapping into a particularly Chinese cultural dynamic and in some cases exploiting it. Chongqing, a sprawling metropolis of 30 million in southwestern China, has required all kindergartens, primary schools, and middle schools to open official WeChat accounts before the end of June this year to streamline communication with parents and students.

For Zehao, the app is a forum for extra homework and a billboard for misbehavior at school, and the group chat puts everything under the scrutinizing eye of the entire class. "The intention was good, because teachers wanted to work closely with parents to improve the children's academic performance," says his mother, Chen Zongying, 43. "But it stresses you out."

One night in January, when schoolchildren all over China were preparing for final exams, Zehao's math teacher called at 10 P.M.: she told him there were mistakes in the geometry drills he had just posted on WeChat. The teacher urged him to correct his drills and post a picture of the rewritten ones as soon as possible so she could review them before midnight. His mother says she sometimes has to silence her phone to avoid the beeps heard as other students file their assignments and the teacher sends reminders.

Experts agree that the messaging app is intensifying the round-the-clock pressure in China's education system. "It infringes on students' privacy and affects the development of their character," says Xiong Bingqi, deputy director of 21st Century Education Research Institute. Even Zehao is skeptical about how WeChat can help students learn better: not only has the app made filing assignments instant, but it has also made sharing and copying completed assignments instant. "The app is actually not that helpful," he says. A spokeswoman for Tencent declined to comment.

For younger students, the use of WeChat is less cutthroat but still intrusive. On his first day of school this spring semester, Li Guibin, a third grader in Tianjin, had the afternoon off for a holiday. After he got home, his math teacher sent a reminder to his class group about the division drills students needed to finish that afternoon, but at least the drills were to be turned in the next morning, not via WeChat on the same day. "When he was in first grade, some parents had very old phones and were not familiar with WeChat," says Guibin's mother, Zhuang Yanfei, 30. "But they all bought new phones and learned to use it."

Not every school goes to such extremes when incorporating WeChat into classrooms. Yan Xu, who teaches third-grade Chinese language and literature in Tianjin, says in addition to informing parents

**It's a forum for homework and a billboard for misbehavior at school.**

of school events, her school uses WeChat only to showcase excellent homework. "If we praise the good ones, other parents will encourage their kids to work hard too," she says.

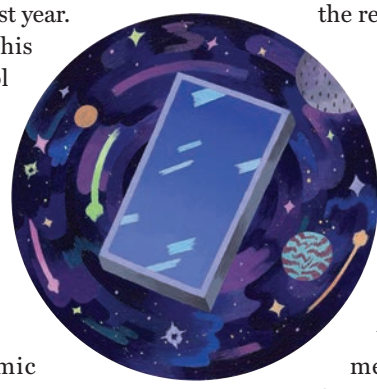
But nurturing young minds takes more than that. "WeChat is just the latest platform that intermediates interactions between teachers, parents, students," says Danah Boyd, a Microsoft researcher who studies social media. "No intervention around the technology will make any difference if the pressure-cooker culture doesn't change." —*Yiting Sun*

COURTESY OF YITING SUN

# Sky-High Air Conditioning

An unconventional approach to cooling sends heat to the cold sky.

**Air conditioning accounts for almost 15** percent of all energy use by buildings in the United States. One way to cut that proportion is to send heat to outer space, according to Aaswath Raman, who was named one of our 35 Technology Innovators Under 35 last year. Raman recently spun his new company, SkyCool Systems, out of Stanford University. The startup is one of several groups commercializing an energy-efficient cooling approach that takes advantage of the coldness of space.



The idea is to mimic a natural, if bizarre, phenomenon called radiative cooling. All objects emit thermal radiation. When it's emitted toward the sky, a portion of it is absorbed and reflected by the atmosphere. Another portion, which falls within a particular range of frequencies, travels into the upper atmosphere and outer space.

The technology SkyCool is developing to exploit this is based on relatively recent advances in the ability to manipulate light at the nanoscale. Engineers have known for a while that radiative cooling is useful for cooling buildings at night. During the day, however, the sun's radiation counteracts the cooling effect. But a few years ago Raman and a colleague at Stanford determined that it should in fact be possible to achieve radiative cooling during the day.

In 2014, the group published a paper in *Nature* in which they showed that a device designed to combine the optical properties of three different materials, arranged in a stack of multiple layers, cooled to nearly 5 °C below the ambient air temperature. This proved that "the cold darkness of the Universe" can be used as a renewable resource, "even during the hottest hours of the day," wrote the researchers.

Raman says his company is exploring a range of potential applications, in the developing as well as the developed world. An existing model for SkyCool's general approach, he says, is the fairly recent development and commercialization of techniques for applying optical coatings to make windows more energy efficient.

Raman says the company has also shown that its prototypes can significantly lower the temperature of water, meaning it should be possible to "plug this into a wide range of cooling and refrigeration systems" that use cooled water to remove heat from the air. For typical buildings in North America, he adds, "you will want to use this in conjunction with an existing cooling or refrigeration system."

Srinivas Katipamula, a staff scientist at the Pacific Northwest National Laboratory who studies advanced heating and cooling concepts, recently conducted a modeling study and found that daytime radiative cooling could reduce the energy consumption of a medium-sized office building by 30 to 50 percent. But it's not yet clear how much the technology will cost. *—Mike Orcutt*

SAM D'ORAZIO; GRAFILU

3 QUESTIONS

## Robert Hannigan

**A lot of people assume spy agencies, including the British signals intelligence agency GCHQ, which you lead, can crack any device. Can't you?**

It still doesn't get around the problem for law enforcement. We can do all sorts of clever target discoveries, and use data in clever ways, but they have to prosecute and produce evidence. And for them it's not about long-term intelligence; it's about a 14-year-old girl who's gone missing, and the parents expect law enforcement to know where she is.

**Do you regret things that your counterparts at NSA did or your predecessors at GCHQ did that Edward Snowden revealed?**

I certainly think it has contributed to the lack of trust. One of the damages was to poison the relationship, make it very difficult for the tech sector to sit down with government at all. I think that's changed. It's softened over time.

**Does the fact that we now know about certain surveillance programs only because of Snowden imply that they were secret because of doubts over whether they were appropriate?**

They were secret because to be effective, they needed to be secret. And obviously, revealing them damages their effectiveness. My general thought, though, on the pre-Snowden [era], if you like, is that it would have been so much easier if we had been much more open about a lot of this stuff. We should have said more in the past about what we did ... and make clear how it's controlled, how it's proportionate, what it's for, which we've tried to do recently.

*—Brian Bergstein*

MIT Technology Review

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# Upfront

## The New Mosquito Menace

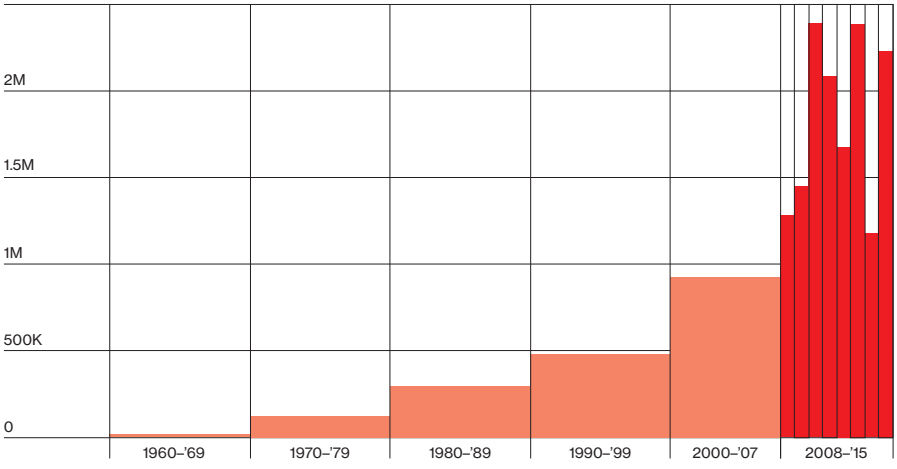
The world's deadliest mosquito-borne disease, malaria, is in decline (see "The Extinction Invention," page 54). But illnesses transmitted by a different mosquito, which include Zika and dengue, have increased sharply since the city-dwelling *Aedes aegypti* reinvaded the Americas.


Eighteen Latin American countries eradicated *Aedes aegypti* in the early 1960s. This map shows where the mosquito was spotted in the Americas.


A more recent map reflecting reports of *Aedes aegypti* illustrates just part of the reinvasion: the insect's range is even more expansive than surveillance efforts have been able to track.

### Dengue Ballooning

Global cases of dengue fever are skyrocketing. During the past decade, the Americas have seen the most dramatic increase, according to the World Health Organization.




### Tiny Insects, Massive Threats

Though it pales next to malaria, Zika is yet another dangerous mosquito-borne illness.

**Malaria**
149 million-303 million
estimated global cases in 2015

**Zika**
185,027
suspected cases in the latest outbreak, which began in late 2014

**Chikungunya**
693,489
suspected cases in 2015

**Yellow fever**
84,000-170,000
estimated annual cases

ILLUSTRATION BY LUKE SHUMAN; MAP DATA FROM KRAEMER ET AL. *NATURE SCIENTIFIC DATA* (2015) AND THE WORLD HEALTH ORGANIZATION. REPORTS ON DENGUE ARE FROM THE AMERICAS, WESTERN PACIFIC, AND SOUTHEAST ASIA. DATA ON ZIKA AND CHIKUNGUNYA ARE FROM THE AMERICAS.

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# Upfront

## A Collar to Protect the Brain

Researchers have begun human clinical trials for a device that's meant to keep the brain from moving around so much inside the skull when it gets hit.

**Could a neck-worn device protect the brains** of athletes and soldiers against traumatic injury? That's the promise of technology that researchers are beginning to test in humans. The idea behind such a "collar," which was originally inspired by studies of animals that tolerate repeated blows to the head, is to slightly increase the amount of blood in the brain and thereby cushion it in a way no helmet can, says Julian Bailes, a co-inventor of the technology, who is chairman of neurosurgery at NorthShore University HealthSystem and co-director of the NorthShore Neurological Institute in Evanston, Illinois.

Studies of the brains of deceased athletes have linked repetitive head trauma to neurodegenerative disease. Bailes, the former Pittsburgh Steelers doctor who was instrumental in first alerting the public to chronic traumatic encephalopathy, or CTE—and who is portrayed by Alec Baldwin in the Hollywood drama *Concussion*—says helmets fall short in protecting against injuries that occur when the brain, which floats in cerebrospinal fluid and is not connected to the skull, "sloshes" around.

**Woodpeckers adjust the pressure in their skulls to keep their brains intact.**

The researchers wanted to find a way to contain that sloshing. It turns out that woodpeckers and bighorn sheep—both of which tolerate repetitive, high-impact blows to the head—may do so by adjusting the pressure and volume inside the skull so that their brains don't slosh. They also looked at data on reported concussions in contact sports and found that concussion rates were roughly 30 percent lower in games played at higher altitude. This could be because the human brain tends to increase in volume at high altitude, giving it less room to move around inside the cranium, says Gregory Myer, director of the human performance laboratory at Cincinnati Children's Hospital.

*The inventors of this device, now being tested in athletes, say it could reduce the risk of brain injury.*

Achieving a tighter fit between the brain and the skull is the idea behind the new collar, a U-shaped device that fits snugly against the back and sides of a person's neck. It applies gentle compression (about as much as a necktie, says Bailes) to the jugular veins, slightly reducing the amount of blood flowing back to the heart after every beat. Tests in rat models suggest that such jugular compression leads to reduced signs of brain injury, and the researchers hypothesize that this is due to a decrease in sloshing.

Myer is also directing human studies, which entail using electroencephalography and advanced magnetic resonance imaging (MRI) to capture information about the brains of athletes—hockey and football players so far—in the preseason, midseason, and postseason. Helmet-mounted accelerometers track the quantity and magnitude of head impacts during competition. In a given experiment, one group of players wears the collar and a control group does not.

Demonstrating the efficacy of this technology will be challenging because scientists still understand very little about the connection between the signs of injury and a person's symptoms. Further, it's not well understood why and to what extent the risk of injury or disease varies from individual to individual, although prospective data sets like the ones Myer is collecting could begin to shed light on these questions.

As for any risks associated with modulating the blood flow between the heart and the brain, Myer says that "safety is by far more important than efficacy at this point," and that the group has had discussions with or solicited opinions from hundreds of physicians about the technology. So far there haven't been any adverse events, he says, but "that's why we have to do the research." *—Mike Orcutt*

COURTESY OF Q30 INNOVATIONS


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MIT Technology Review

# Upfront

## Daredevil Drones

Startup Skydio has developed a more sophisticated autopilot for drones. Beyond obstacle avoidance, it lets an aircraft orient itself and navigate through busy areas.

**On a recent bike ride through the woods** near Menlo Park, California, Adam Bry, CEO of a company called Skydio, was joined by a small, nimble drone. As he rode along a dirt track, the drone followed close by, weaving expertly around tree trunks and branches in a series of deft maneuvers.

What's amazing is that the drone wasn't piloted by a person but by Skydio's technology. It lets an unmanned aerial vehicle (UAV) use several video cameras to avoid obstacles and to navigate at high speeds through busy airspace as capably as a human pilot. That kind of autonomy could transform the consumer drone market by making aircraft much harder to crash. It could also make it easier for drones to do tasks autonomously even in active settings. "The motivation for the company is giving the thing the agility, attention, and awareness that an expert pilot has," Bry says. He declined to say when Skydio's first product would appear or how much it might cost.

Flying autonomously is more difficult than driving because the hardware needs to be compact and light, and because even the slightest miscalculation can result in disaster. The drone developed by Skydio uses a camera together with vision-processing software that lets the aircraft determine where it is in space and identify and avoid obstacles. Bry developed the necessary algorithms with Abraham Bachrach, Skydio's chief technology officer, while both were students at MIT. The techniques they came up with made it possible for drones to navigate through unfamiliar indoor spaces safely and for a plane with a two-foot wingspan to weave its way around a busy garage without crashing.

Nick Roy, a professor of robotics who advised Bry and Bachrach at MIT, expects aerial vehicles to become more common for surveillance and inspection tasks. But he adds that reliable autopilot, toward which Skydio has taken a significant step, is a key missing piece of that picture. "If we want these things to provide all the services people are hoping for in terms of infrastructure inspection, precision agriculture, filming in various ways—that's going to require autonomy," Roy says.

Today, most drones are controlled remotely or are only capable of basic automation. A few drones are starting to come with more advanced obstacle identification and avoidance, but none is as sophisticated as Skydio's prototype. The latest drone from Chinese company DJI, the Phantom 4, uses several cameras to spot impediments, and it will override the controller's actions if it seems likely to run into something. It can also track moving objects using its vision system, but it doesn't perform the kind of mapping and navigation that Skydio's drone does.

"Navigation is absolutely crucial, especially in flight," says Lora Weiss, chief scientist of the Georgia Institute of Technology's Institute for Intelligent Machines. Weiss is working on projects involving UAVs with even more advanced autonomy. Some of the systems she is developing are, for example, able to deviate from a given course if they spot something of interest, and then call for help from other aircraft. "The nimbleness in navigation is really going to be crucial for where these things are going," Weiss says. *—Will Knight*

**TO MARKET**

### Here Active Listening

**Sound-enhancing earbuds**

**COMPANY:**
Doppler Labs

**PRICE:**
$199–$299

**AVAILABILITY:**
Late 2016

**The superhuman ability to tune out certain noises is now available** in a pair of wireless Bluetooth earbuds called Here Active Listening. They work with a smartphone app to change the way you hear anything from rock concerts to construction noise. Created by a startup called Doppler Labs, Here lets you swipe to adjust the volume on a conversation you're having with a friend who's standing in front of you (or, say, turn down a TV show without having to change the sound level for anyone else who's watching). There are also eight different filters, still in beta, meant for eliminating noise in specific situations—on a subway, bus, plane, or office, for instance. *—Rachel Metz*

TIM LAHAN, COURTESY OF DOPPLER LABS


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# Upfront

**QUOTED**

### "That's one of the biggest limiting factors right now—the computing power."

—Oculus founder Palmer Luckey on the challenge of getting high-quality virtual reality without the cost of a powerful PC.

### "It works overnight; the next morning it is tuned."

—Shohei Hido, chief research officer at Preferred Networks, which programmed an industrial robot to learn a new task in just eight hours.

### "We could have an accident occur with gene editing that is catastrophic."

—Daniel Gerstein, senior policy analyst at RAND and a former undersecretary at the Department of Homeland Security, after the government said gene editing is a potential weapon of mass destruction.

**BY THE NUMBERS**

### $7.50

Cost per person per year for the city of Piracicaba, Brazil, to protect its 390,000 residents from the Zika virus using genetically modified mosquitoes from Oxitec.

### 90%

Proportion of new global electricity generation that came from renewable energy in 2015, according to the International Energy Agency.

### 10 years

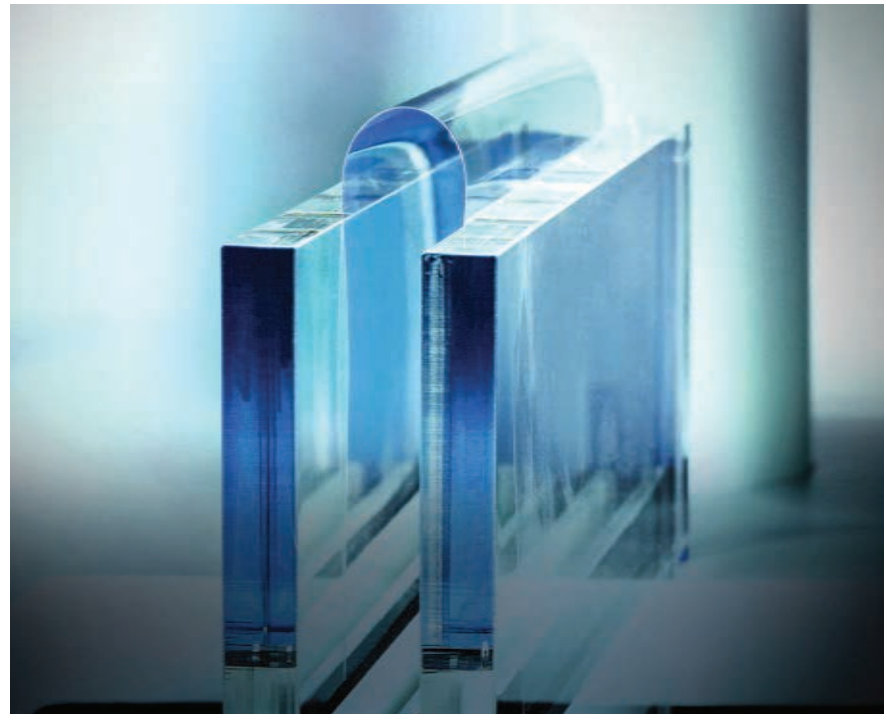
Time until virtual reality becomes mainstream, according to Facebook CEO Mark Zuckerberg.

### $9.25

Monthly subsidy offered by the government to low-income households to offset the cost of broadband Internet service.

## Flexible Glass

Schott can make a bendable sheet of glass thinner than a hair and half a kilometer long, but it doesn't yet fold.



*Schott is the first company to make ultrathin glass that can be chemically strengthened by ion exchange.*

COURTESY OF SCHOTT

**Imagine a flip phone that fits in your pocket** but opens up to reveal a tablet-sized screen. Glassmakers are already manufacturing bendable glass that's thinner than a human hair, and they say foldable glass is just around the corner.

German glassmaker Schott is now mass-manufacturing glass that's ultrathin, strong, and smooth. Electronics can be made on it, and it flexes like plastic. The first consumer product to use Schott's new glass is the fingerprint sensor on a smartphone made by LeTV, a large video-streaming company in China. Company representatives hope that this and other niche applications will give the new material a foothold while industrial designers play around with it.

Rüdiger Sprengard, director of business development for ultrathin glass at Schott in Mainz, Germany, says the company can now continuously manufacture flexible glass in kilometers-long sheets. Sprengard recently brought some demos to show off in a San Francisco hotel room. He showed me a spool of glass half a meter wide and half a kilometer long; it looked like a fat roll of cellophane. A machine repeatedly bent a smaller piece of the glass down to a radius of nine millimeters. It doesn't fold yet, but Sprengard says they're working on it

and hope to have it in a few years. After giving me gloves and goggles, Sprengard handed me a sheet about the size of a sheet of office paper, but thinner and stiffer. Paper is about 100 micrometers thick; this sheet was 70 micrometers. As I flopped it around in my hands, treating it like a piece of plastic, one of the company representatives stepped back. It's still glass, after all, and she wasn't wearing any eye protection. When they first started experimenting with making glass this thin, it broke much more easily, Sprengard explains. "About two years ago you wouldn't have been able to handle it like that," he says.

That fragility is why mass production of flexible glass has been so challenging. To make it work, Schott had to develop new methods that built on those already used to make ultrastrong glass like Corning's Gorilla Glass, which is found on the surface of many smartphones. Gorilla Glass and other products made by both companies are toughened through a process called ion exchange.

To make glass thinner and thinner, and therefore more flexible, glassmakers have to figure out how to strengthen it. Schott is the first company to make ultrathin glass that can be chemically strengthened by ion exchange, which was a challenge, says Eric Urruti, vice president of R&D at Schott North America in Pennsylvania. Molten glass is drawn down out of a huge tank into sheets and run through rollers. The sheets are then run through a bath of molten potassium. Smaller sodium ions leave the glass and are replaced by larger potassium ions, creating compression within the glass itself.

The more the glass is squeezed, the stronger it becomes. Controlling this compressive process in ever-thinner glass is difficult—there's simply less material to work with. The company currently makes glass as thin as 20 micrometers. Maintaining continuous thickness across kilometers is also a challenge. And any tiny flaws must be smoothed over—or that's where your phone screen will shatter.

**Compared with plastic, glass will always have superior puncture resistance.**

As the glass gets thinner, the challenges change, says Scott Forester, director of Gorilla Glass Innovations at Corning, headquartered in New York. Corning, which is also developing ultrathin glass, sells a product that's 100 micrometers thick. As cover glass (the kind found on the surface of phones) gets thinner, it's more vulnerable to being punctured. Forester says that compared with plastic, glass will always have superior puncture resistance, and they continually run tests to prove it.

Flexible electronics are already making some headway, but not in a way that's obvious to consumers. Today, flexible screens are used in devices like the Galaxy Edge, a phone with a rigid screen that curves at the sides. The OLED display within the phone is made on plastic and laminated to a Corning Gorilla Glass coverslip. If that cover glass were flexible, it would be an important step toward a device that itself could be flexible. Cover glass today is 10 times thicker than the glass Schott is showing off—usually about 550 micrometers (half a millimeter).

Forester says the pieces are in place for more flexible consumer electronics. The glass is ready and the flexible circuits are almost ready. Now they're waiting for the designers—and for consumers. "There has to be a form factor that adds value for people," he says. Right now it's not clear what that will be. But Corning is also working on glass that will make it possible. Since ion exchange becomes more difficult in thinner materials, the company is looking at altering the underlying matrix of the glass itself—a more fundamental change in the material. Humans have been using glass since the Stone Age, but there's still a lot more chemistry to explore, says Forester: "Our scientists test 30 or 40 new glasses each day." *—Katherine Bourzac*

**TO MARKET**

## Phoenix

**Robotic exoskeleton**

**COMPANY:**
SuitX

**PRICE:**
$40,000

**AVAILABILITY:**
Now

COURTESY OF SUITX

**Paralyzed from the waist down after a BMX accident, Steven** Sanchez rolled into SuitX's Berkeley, California, office in a wheelchair. A half-hour later he was standing and walking thanks to the Phoenix, a 27-pound robotic exoskeleton. The suit returns movement to wearers' hips and knees with small motors attached to standard orthotics. Wearers can control the movement of each leg and walk at up to 1.1 miles per hour by pushing buttons integrated into a pair of crutches. The suit is also adjustable so it can adapt to, say, a relatively tall person who just needs mobility assistance for one knee. A battery pack worn as a backpack powers the exoskeleton for up to eight hours. *—Signe Brewster*

# Q+A

*Wael Ghonim addresses a crowd in Cairo's Tahrir Square in 2011.*

DYLAN MARTINEZ/REUTERS

# Remaking Social Media for the Next Revolution

In 2011, Wael Ghonim was a Google executive in Cairo who helped launch the Egyptian revolution. His Facebook page, expressing outrage about a young man killed by police, became a rallying point for protests that led to the ouster of President Hosni Mubarak (see "Streetbook," September/October 2011). But the story line of the Arab Spring soon changed. The online movement polarized into factions. The new military-led government figured out how to promote itself online—and a 2013 coup crushed what dissent remained. Ghonim had to leave the country and is now in Silicon Valley working on new social-networking tools. To discuss the promise and limits of using the Internet to facilitate political change, Ghonim spoke with Zeynep Tufekci, an assistant professor at the University of North Carolina who studies online social movements. The discussion was edited by David Talbot, *MIT Technology Review*'s senior writer.

**Tufekci: What was the most important role the Internet played in helping people launch the Egyptian revolution in 2011?**
Ghonim: The Internet is such a great tool for knowledge-sharing and community organizing. If you are angry politically in any democratic country, you probably have choices, such as joining a party or supporting a certain candidate. None of this was present in Egypt, but there were a lot of people who were unhappy with the regime and with decades of corruption, torture, and failure to run the country.

A decentralized, flat organization started to emerge—especially on Facebook—and created an opportunity for this movement to prosper. It was very hard to attack it and shut it down. I was com-

pletely apolitical until Mohamed ElBaradei [a prominent Egyptian diplomat] announced he might get involved in Egyptian politics. A group supporting him on Facebook included 20 or 30 of my friends and had probably about 100,000 members. For me, I joined the movement and it was "Wow—there are 100,000 people on Facebook in Egypt who think like me!"

**Tufekci: What would you say are some of the biggest lessons you learned?**
Ghonim: Social media offered a decentralized way for those who are not in power, or in control of media, to broadcast and communicate. But to a large extent this is a double-edged sword. You could use that to raise awareness, defend human rights, and try and rescue people whose rights were being violated. But at the same time the government learned how to use it to broadcast misinformation and propaganda, and online dynamics helped create a polarized environment as well.

**Tufekci: What are you referring to?**
Ghonim: Instead of constructive dialogue about the way forward, there were bitter flame wars among many groups—sometimes among friends. Rather than uniting to take the country forward, the conversation descended into bickering, propaganda, many false claims, and fearmongering.

**Tufekci: Five years ago, fresh from the events of the Egyptian revolution, you said the Internet alone could create a free society. Do you still believe that?**
Ghonim: In 2011 I did say that if you want to liberate a society all you need is the Internet. However, whereas Mubarak had largely ignored the Internet, the current regime uses the Internet in a much better way—drowning out dissident voices amidst its own propaganda and also conducting a campaign of terrorizing those who speak out online. Five years ago I thought the Internet was a power that was granted to the people and that would never be weakened. But I was wrong.

**Tufekci: There's another issue. Many of the tools activists rely on to organize and broadcast their message don't facilitate deliberation. They are also based on what's called the "attention economy," where the loudest voices can get more attention. This facilitates polarization, but you can't really argue things out.**
Ghonim: Yes. The current social-media currency is based on likes, shares, and retweets. People are more interested in broadcasting their opinions than engaging in discussions. I once sarcastically said that I feel like it is much harder to actually stand up against the mainstream on Twitter than stand up against a dictator, because at least when I stand up against a dictator I know there are a lot of people who will support me. But when you stand up against the Twitter mainstream, they are just going to all go against you.

To be sure, there is no doubt that the Internet actually helps facilitate communication and shows the power of crowdsourcing in positive action, especially when it comes to the humanitarian activities like when there is a hurricane or a terrorist attack. The problem is, however, that the negatives are obvious and not talked about enough.

**Tufekci: This has happened in many countries. When you're organizing a protest or where you're coming together, social media is a very potent tool. What I observed, and I think your experience bears this out, is that the problem starts in the second stage or the third stage. What do you do after you've occupied the "Square" or the "Park" and the government starts countermoves? How do you think these movements that are fueled by social media will evolve to tackle these problems?**
Ghonim: I think there will be an evolution. For Egypt, our conversation today is not how to start the next Facebook page. The biggest question we keep asking ourselves is "How can we organize our next movement? How could we convert the energy and passion of people into a way that is constructive and beneficial for the country?" Because we know for a fact now that just protesting is not going to solve the country's problems.

**Tufekci: Your social-media platform, which you called Parlio, was just acquired by the question-and-answer site Quora. What's the goal of this platform?**
Ghonim: Can you create an online culture where everybody is civil? Can you have tools that facilitate this? This platform is a community of authors, journalists, students, academics, businesspeople, and other curious and insightful thinkers from around the world. Anyone can read and post questions. One of the things we noticed is how, after writing articles in other top publications, the writers took their discussions to our site. They shared and engaged in elaborate discussions with members of the community. This tells you that people are ready to engage with each other even if there is strong disagreement, which happens to be the case in many of these articles. I believe that the Internet has a lot of potential here.

**Tufekci: But do you think this can scale and reach ordinary masses of people, like the ones who thronged to Cairo's Tahrir Square in 2011?**
Ghonim: Yes. I believe that it's possible to build an experience that motivates thoughtful and civil conversations at scale. This was one of the motivations of our team joining forces with Quora, which has more than 100 million unique users a month.

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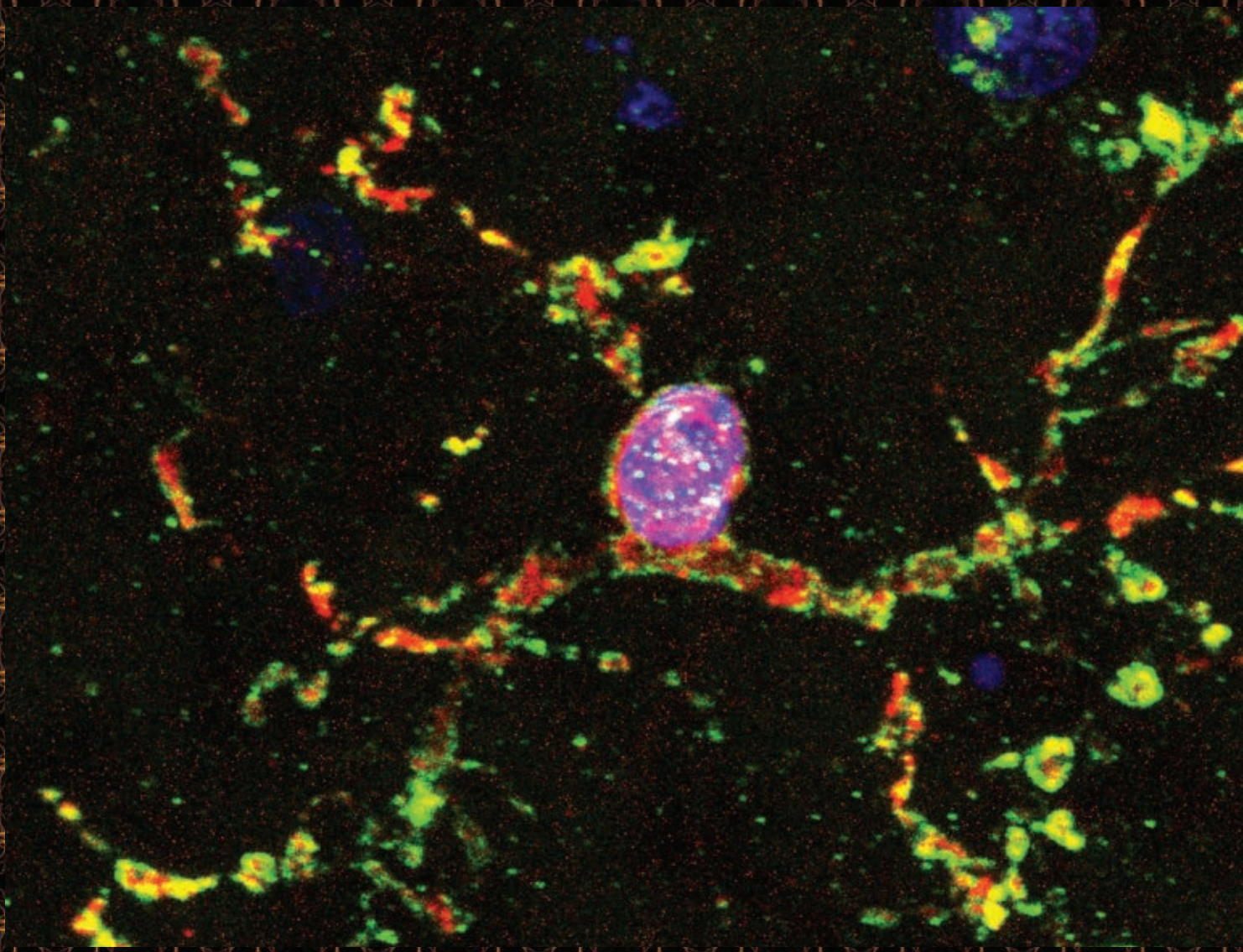
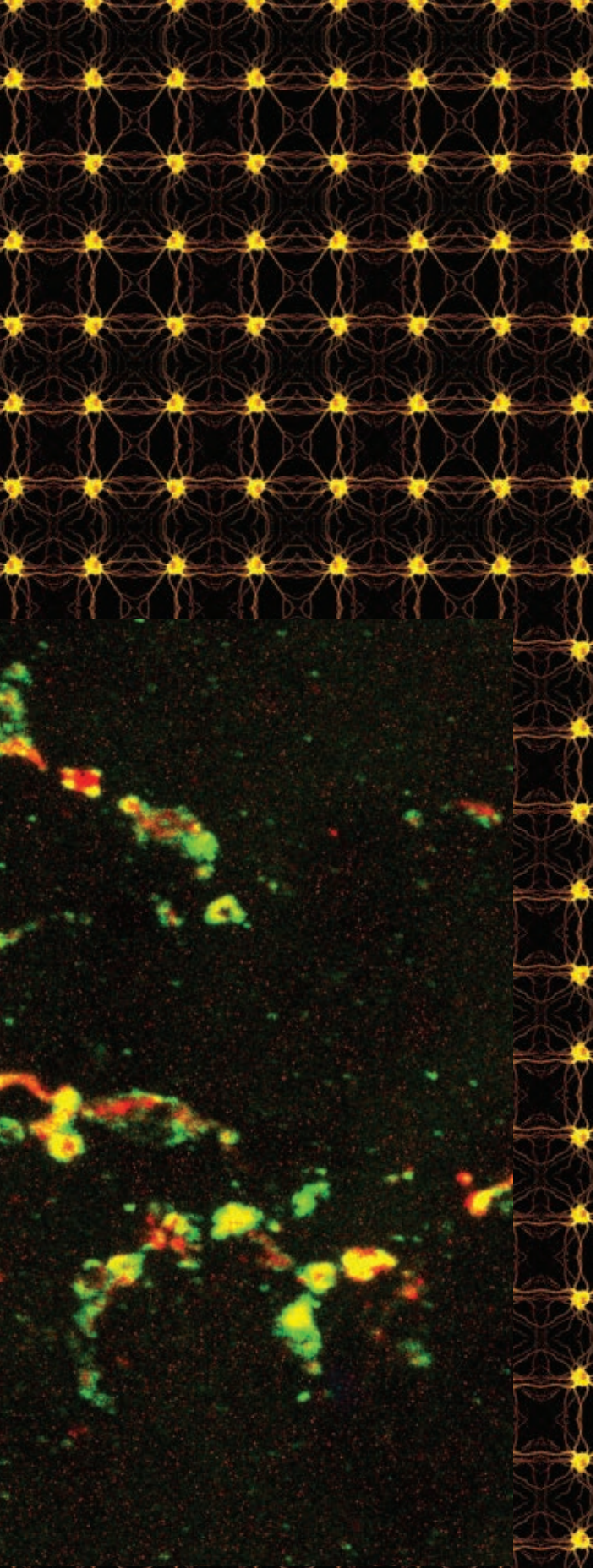
# The Rogue Immune Cells That Wreck the Brain

Beth Stevens thinks she has solved a mystery behind brain disorders such as Alzheimer's and schizophrenia.

By Adam Piore





MICROGLIA COURTESY OF BEN BARRES, MARIKO L. BENNETT, AND FREDERICK CHRISTIAN
BENNETT; NEURON BACKGROUND IMAGE COURTESY OF MOLLIE WOODWORTH

In the first years of her career in brain research, Beth Stevens thought of microglia with annoyance if she thought of them at all. When she gazed into a microscope and saw these ubiquitous cells with their spidery tentacles, she did what most neuroscientists had been doing for generations: she looked right past them and focused on the rest of the brain tissue, just as you might look through specks of dirt on a windshield.

"What are they doing there?" she thought. "They're in the way."

Stevens never would have guessed that just a few years later, she would be running a laboratory at Harvard and Boston's Children's Hospital devoted to the study of these obscure little clumps. Or that she would be arguing in the world's top scientific journals that microglia might hold the key to understanding not just normal brain development but also what causes Alzheimer's, Huntington's, autism, schizophrenia, and other intractable brain disorders.

Microglia are part of a larger class of cells—known collectively as glia—that carry out an array of functions in the brain, guiding its development and serving as its immune system by gobbling up diseased or damaged cells and carting away debris. Along with her frequent collaborator and mentor, Stanford biologist Ben Barres, and a growing cadre of other scientists, Stevens, 45, is showing that these long-overlooked cells are more than mere support workers for the neurons they surround. Her work has raised a provocative suggestion: that brain disorders could somehow be triggered by our own bodily defenses gone bad.

In one groundbreaking paper, in January, Stevens and researchers at the Broad Institute of MIT and Harvard showed that aberrant microglia might play a role in schizophrenia—causing or at least contributing to the massive cell loss that can leave people with devastating cognitive defects. Crucially, the researchers pointed to a chemical pathway that might be targeted to slow or stop the disease. In March, Stevens and other researchers published a similar finding for Alzheimer's.

This might be just the beginning. Stevens is also exploring the connection between these tiny structures and other neurological diseases—work that earned her a $625,000 MacArthur Foundation "genius" grant last September.

All of this raises intriguing questions. Is it possible that many common brain disorders, despite their wide-ranging symptoms, are caused or at least worsened by the same culprit, a component of the immune system? If so, could many of these disorders be treated in a similar way—by stopping these rogue cells?

*A microglial cell from a human brain, stained for research purposes.*

**Complex machinery**

It's not surprising that scientists for years have ignored microglia and other glial cells in favor of neurons. Neurons that fire together allow us to think, breathe, and move. We see, hear, and feel using neurons, and we form memories and associations when the connections between different neurons strengthen at the junctions between them, known as synapses. Many neuroscientists argue that neurons create our very consciousness.

Glia, on the other hand, have always been considered less important and interesting. They have pedestrian duties such as supplying nutrients and oxygen to neurons, as well as mopping up stray chemicals and carting away the garbage.

Scientists have known about glia for some time. In the 1800s, the pathologist Rudolf Virchow noted the presence of small round cells packing the spaces between neurons and named them "nervenkitt" or "neuroglia," which can be translated as nerve putty or glue. One variety of these cells, known as astrocytes, was defined in 1893. And then in the 1920s, the Spanish scientist Pio del Río Hortega developed novel ways of staining cells taken from the brain. This led him to identify and name two more types of glial cells, including microglia, which are far smaller than the others and are characterized by their spidery shape and multiple branches. It is only when the brain is damaged in adulthood, he suggested, that microglia spring to life—rushing to the injury, where it was thought they helped clean up the area by eating damaged and dead cells. Astrocytes often appeared on the scene as well; it was thought that they created scar tissue.

This emergency convergence of microglia and astrocytes was dubbed "gliosis," and by the time Ben Barres entered medical school in the late 1970s, it was well established as a hallmark of neurodegenerative diseases, infection, and a wide array of other medical conditions. But no one seemed to understand why it occurred. That intrigued Barres, then a neurologist in training, who saw it every time he looked under a microscope at neural tissue in distress. "It was just really fascinating," he says. "The great mystery was: what is the point of this gliosis? Is it good? Is it bad? Is it driving the disease process, or is it trying to repair the injured brain?"

Barres began looking for the answer. He learned how to grow glial cells in a dish and apply a new recording technique to them. He could measure their electrical qualities, which determine the biochemical signaling that all brain cells use to communicate and coördinate activity.

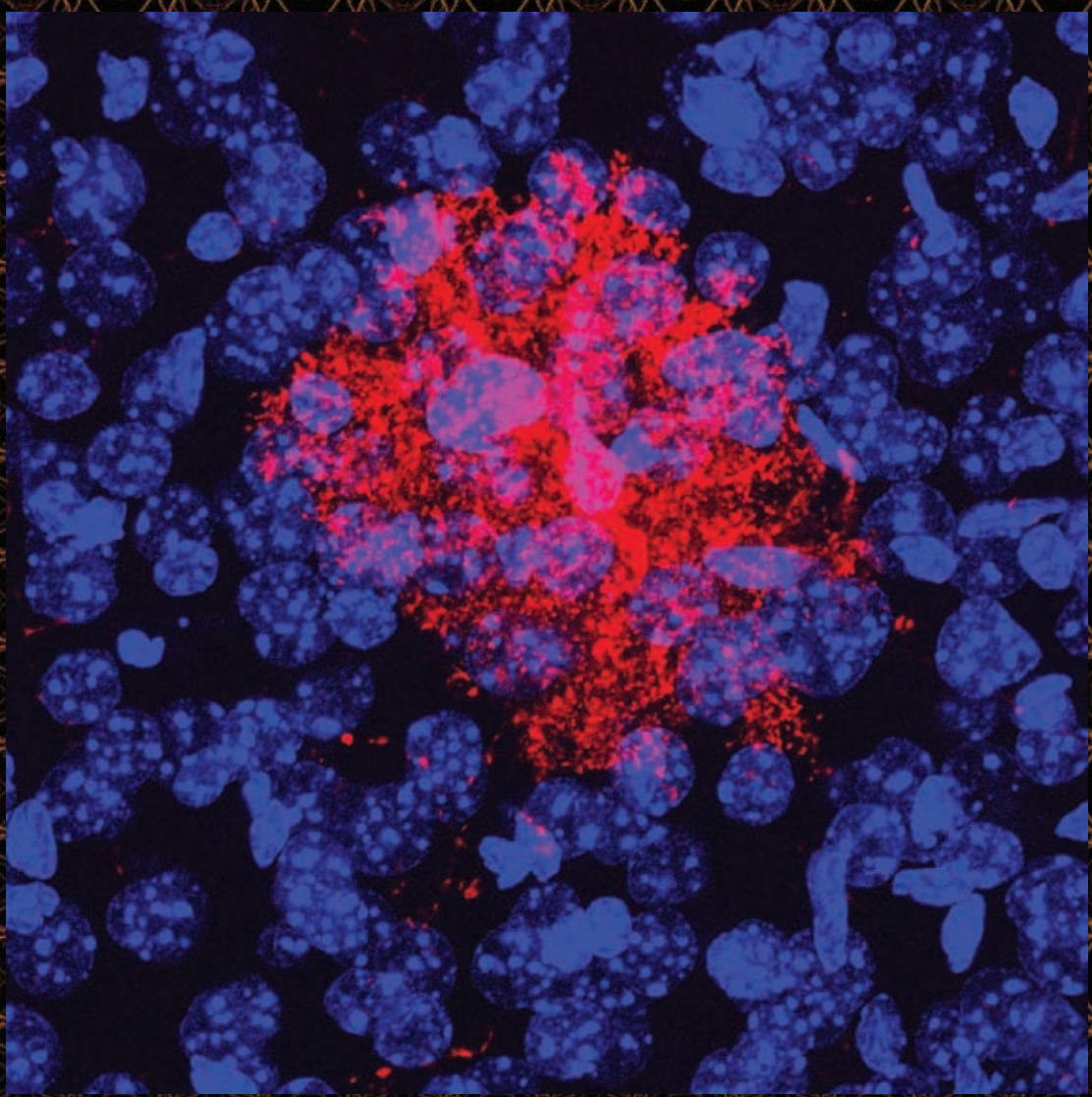
"From the second I started recording the glial cells, I thought 'Oh, my God!'" Barres recalls. The electrical activity was more dynamic and complex than anyone had thought. These strange electrical properties could be explained only if the glial cells were attuned to the conditions around them, and to the signals released from nearby neurons. Barres's glial cells, in other words, had all the machinery necessary to engage in a complex dialogue with neurons, and presumably to respond to different kinds of conditions in the brain.

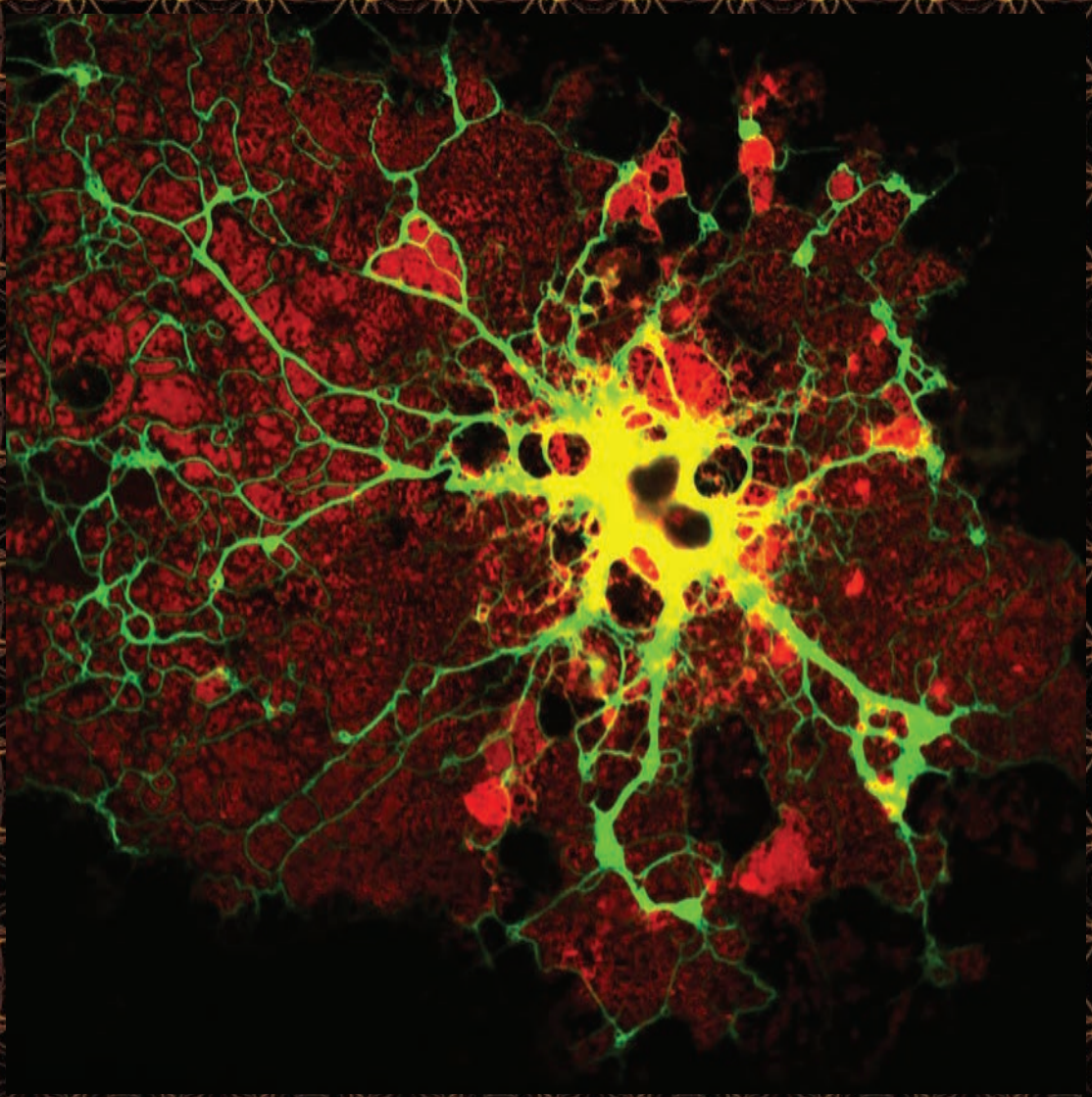
Why would they need this machinery, though, if they were simply involved in cleaning up dead cells? What could they possibly be doing? It turns out that in the absence of chemicals released by glia, the neurons committed the biochemical version of suicide. Barres also showed that the astrocytes appeared to play a crucial role in forming synapses, the microscopic connections between neurons that encode memory. In isolation, neurons were capable of forming the spiny appendages necessary to reach the synapses. But without astrocytes, they were incapable of connecting to one another.

Hardly anyone believed him. When he was a young faculty member at Stanford in the 1990s, one of his grant applications to the National Institutes of Health was rejected seven times. "Reviewers kept saying, 'Nah, there's no way glia could be doing this,'" Barres recalls. "And even after we published two papers in *Science* showing that [astrocytes] had profound, almost all-

*This page: Beth Stevens in her lab in Boston. Opposite: a stained astrocyte.*

M. SCOTT BRAUER; ASTROCYTE COURTESY OF BEN BARRES AND LU SUN





or-nothing effects in controlling synapses' formation or synapse activity, I still couldn't get funded! I think it's still hard to get people to think about glia as doing anything active in the nervous system."

**Marked for elimination**

Beth Stevens came to study glia by accident. After graduating from Northeastern University in 1993, she followed her future husband to Washington, D.C., where he had gotten work in the U.S. Senate. Stevens had been pre-med in college and hoped to work in a lab at the National Institutes of Health. But with no previous research experience, she was soundly rebuffed. So she took a job waiting tables at a Chili's restaurant in nearby Rockville, Maryland, and showed up at NIH with her résumé every week.

After a few months, Stevens received a call from a researcher named Doug Fields, who needed help in his lab. Fields was studying the intricacies of the process in which neurons become insulated in a coating called myelin. That insulation is essential for the transmission of electrical impulses.

As Stevens spent the following years pursuing a PhD at the University of Maryland, she was intrigued by the role that glial cells played in insulating neurons. Along the way, she became familiar with other insights into glial cells that were beginning to emerge, especially from the lab of Ben Barres. Which is why, soon after completing her PhD in 2003, Stevens found herself a postdoc in Barres's lab at Stanford, about to make a crucial discovery.

Barres's group had begun to identify the specific compounds astrocytes secreted that seemed to cause neurons to grow synapses. And eventually, they noticed that these compounds also stimulated production of a protein called C1q.

Conventional wisdom held that C1q was activated only in sick cells—the protein marked them to be eaten up by immune cells—and only outside the brain. But Barres had found it in the brain. And it was in healthy neurons that were arguably at their most robust stage: in early development. What was the C1q protein doing there?

The answer lies in the fact that marking cells for elimination is not something that happens only in diseased brains; it is also essential for development. As brains develop, their neurons form far more synaptic connections than they will eventually need. Only the ones that are used are allowed to remain. This pruning allows for the most efficient flow of neural transmissions in the brain, removing noise that might muddy the signal.

COURTESY OF BEN BARRES AND MENG-MENG FU

*A type of glial cell known as an oligodendrocyte.*

But it was unknown how exactly the process worked. Was it possible that C1q helped signal the brain to prune unused synapses? Stevens focused her postdoctoral research on finding out. "We could have been completely wrong," she recalls. "But we went for it."

It paid off. In a 2007 paper, Barres and Stevens showed that C1q indeed plays a role in eliminating unneeded neurons in the developing brain. And they found that the protein is virtually absent in healthy adult neurons.

Now the scientists faced a new puzzle. Does C1q show up in brain diseases because the same mechanism involved in pruning a developing brain later goes awry? Indeed, evidence was already growing that one of the earliest events in neurodegenerative diseases such as Alzheimer's, Parkinson's, and Huntington's was significant loss of synapses.

When Stevens and Barres examined mice bred to develop glaucoma, a neurodegenerative disease that kills neurons in the optic system, they found that C1q appeared long before any other detectable sign that the disease was taking hold. It cropped up even before the cells started dying.

This suggested the immune cells might in fact cause the disease, or at the very least accelerate it. And that offered an intriguing possibility: that something could be made to halt the process. Barres founded a company, Annexon Biosciences, to develop drugs that could block C1q. A paper published in March by Barres, Stevens, and other researchers shows that a compound being tested by Annexon appears to be able to prevent the onset of Alzheimer's in mice bred to develop the disease. Now the company hopes to test it in humans in the next two years.

**Paths to treatments**

To better understand the process that C1q helps trigger, Stevens and Barres wanted to figure out what actually plays the role of Pac-Man, eating up the synapses marked for death. It was well known that white blood cells known as macrophages gobbled up diseased cells and foreign invaders in the rest of the body. But macrophages are not usually present in the brain. For their theory to work, there had to be some other mechanism. And further research has shown that the cells doing the eating even in healthy brains are those mysterious clusters of material that Beth Stevens, for years, had been gazing right past in the microscope—the microglia that Río Hortega identified almost 100 years ago.

Now Stevens's lab at Harvard, which she opened in 2008, devotes half its efforts to figuring out what microglia are doing and what causes them to do it. These cells, it turns out, appear in the mouse embryo at day eight, before any other brain cell, which suggests they might help guide the rest of brain develop-

ment—and could contribute to any number of neurodevelopmental diseases when they go wrong.

Meanwhile, she is also expanding her study of the way different substances determine what happens in the brain. C1q is actually just the first in a series of proteins that accumulate on synapses marked for elimination. Stevens has begun to uncover evidence that there is a wide array of protective "don't eat me" molecules too. It's the balance between all these cues that regulates whether microglia are summoned to destroy synapses. Problems in any one could, conceivably, mess up the system.

We might finally go after diseases that have run unchecked for generations.

Evidence is now growing that microglia are involved in several neurodevelopmental and psychiatric problems. The potential link to schizophrenia that was revealed in January emerged after researchers at the Broad Institute, led by Steven McCarroll and a graduate student named Aswin Sekar, followed a trail of genetic clues that led them directly to Stevens's work. In 2009, three consortia from around the globe had published papers comparing DNA in people with and without schizophrenia. It was Sekar who identified a possible pattern: the more a specific type of protein was present in synapses, the higher the risk of developing the disease. The protein, C4, was closely related to C1q, the one first identified in the brain by Stevens and Barres.

McCarroll knew that schizophrenia strikes in late adolescence and early adulthood, a time when brain circuits in the prefrontal cortex undergo extensive pruning. Others had found that areas of the prefrontal cortex are among those most ravaged by the disease, which leads to massive synapse loss. Could it be that over-pruning by rogue microglia is part of what causes schizophrenia?

To find out, Sekar and McCarroll got in touch with Stevens, and the two labs began to hold joint weekly meetings. They soon demonstrated that C4 also had a role in pruning synapses in the brains of young mice, suggesting that excessive levels of the protein could indeed lead to over-pruning—and to the thinning out of brain tissue that appears to occur as symptoms such as psychotic episodes grow worse.

If the brain damage seen in Parkinson's and Alzheimer's stems from over-pruning that might begin early in life, why don't symptoms of those diseases show up until later? Barres thinks he knows. He notes that the brain can normally compensate for injury by rewiring itself and generating new synapses. It also contains a lot of redundancy. That would explain why patients with Parkinson's disease don't show discernible symptoms until they have lost 90 percent of the neurons that produce dopamine.

It also might mean that subtle symptoms could in fact be detected much earlier. Barres points to a study of nuns published in 2000. When researchers analyzed essays the nuns had written upon entering their convents decades before, they found that women who went on to develop Alzheimer's had shown less "idea density" even in their 20s. "I think the implication of that is they could be lifelong diseases," Barres says. "The disease process could be going on for decades and the brain is just compensating, rewiring, making new synapses." At some point, the microglia are triggered to remove too many cells, Barres argues, and the symptoms of the disease begin to manifest fully.

Turning this insight into a treatment is far from straightforward, because much remains unclear. Perhaps an overly aggressive response from microglia is determined by some combination of genetic variants not shared by everyone. Stevens also notes that diseases like schizophrenia are not caused by one mutation; rather, a wide array of mutations with small effects cause problems when they act in concert. The genes that control the production of C4 and other immune-system proteins may be only part of the story. That may explain why not everyone who has a C4 mutation will go on to develop schizophrenia.

Nonetheless, if Barres and Stevens are right that the immune system is a common mechanism behind devastating brain disorders, that in itself is a fundamental breakthrough. Because we have not known the mechanisms that trigger such diseases, medical researchers have been able only to alleviate the symptoms rather than attack the causes. There are no drugs available to halt or even slow neurodegeneration in diseases like Alzheimer's. Some drugs elevate neurotransmitters in ways that briefly make it easier for individuals with dementia to form new synaptic connections, but they don't reduce the rate at which existing synapses are destroyed. Similarly, there are no treatments that tackle the causes of autism or schizophrenia. Even slowing the progress of these disorders would be a major advance. We might finally go after diseases that have run unchecked for generations.

"We're a ways away from a cure," Stevens says. "But we definitely have a path forward."

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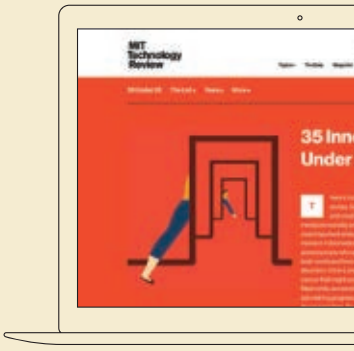
*Adam Piore is a freelance writer who wrote "A Shocking Way to Fix the Brain" in November/December 2015.*





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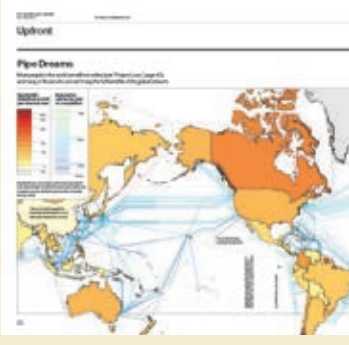



# Q&A: Bill Gates

Microsoft's cofounder vows to change the "supply side" for breakthrough energy technologies by investing billions of his and his friends' dollars.

NEALE HAYNES/GETTY

The world's richest man and his wife write an open letter every year in which they ponder the opportunities for the Bill and Melinda Gates Foundation, the world's largest philanthropic foundation. Last year, they wrote about inequity.

This year, inspired by a question from high school students—"What superpower do you wish you had?"—they wrote separate letters to students, with rather charming annotations in the letters' margins. Melinda answered, "More time!" and wrote about recognizing, redistributing, and reducing the unpaid work that women do, especially in the poor world. Bill said, "More energy!" and wrote about the civilizational challenge of climate change and the imperative to develop what he has for some years been calling "energy miracles."

By "miracles" Gates doesn't mean unanticipated gifts that appear undeserved from nowhere but, rather, technological breakthroughs "that are the result of research and development and the human capacity to innovate," such as the personal computer, the Internet, and the polio vaccine. He called upon students to "work extra hard in your math and sciences," because the world needs "crazy-sounding ideas to solve our energy challenge."

Gates is animated by an equation he claims to have come up with (although it resembles another equation, called the Kaya Identity, well known to climate scientists) that considers total carbon dioxide emissions as the product of the factors P (population), S (services consumed per person), E (the energy used to supply those services), and C (the amount of carbon emitted per unit of energy). If total carbon emissions are to be zero, Gates reasons, and P, S, and E are either going to increase or not go down much, then C must be zero. For C to be zero, we need a miracle or many miracles.

Gates doesn't blame the paucity of miracle technologies on the absence of a price on carbon (which means energy companies have no incentive to develop and deploy carbon-neutral technologies), or on other bad policies. Hundreds of billions of dollars have been spent on what he calls the "demand side" of the energy challenge. Instead, he argues, the fault is underinvestment by governments and private investors in the "supply side," which funds basic government research and resulting startups. In November, Gates decided to do something about that, announcing the Breakthrough Energy Coalition. It brings together more than 20 billionaires, including Amazon's Jeff Bezos, Virgin's Richard Branson, and Facebook's Mark Zuckerberg, who have promised to invest at least $2 billion in breakthroughs.

Jason Pontin, *MIT Technology Review*'s editor in chief, spoke to Bill Gates about how to make C zero and simultaneously satisfy the poor world's legitimate desire to lift billions out of poverty, and about where the coalition will invest its money.

*In fact, many consider Gates's emphasis on "miracle" technological breakthroughs misplaced. See, for example, the physicist and author Joe Romm, writing on the site Climate Progress: "What is particularly unfortunate about Gates's mistaken rhetoric is [his assertion] that our only hope is some long-term deus ex machina strategy to avoid catastrophic warming."*

*It should be noted that neither the PC revolution, the dawn of the Internet, nor the polio vaccine depended on rapid transformation of an existing global industry that is fundamental to the modern way of life, such as the energy sector.*

*Devised by Japanese energy economist Yoichi Kaya, the Kaya Identity is a specific application of the I=PAT equation, which measures environmental impacts (I) in terms of population (P), affluence (A), and technology (T). Kaya splits T into two related factors (energy use per unit of GDP and carbon emissions per unit of energy consumed), using GDP per capita to measure affluence. Gates's version simply substitutes "services" for GDP per capita.*

*Negative emissions—i.e., removing carbon dioxide from the air—would require a technological miracle.*

*Parsons (1854–1931) revolutionized electricity generation and naval warfare just in time for the world wars of the 20th century. His steam turbines, which used multiple stages to extract the maximum kinetic energy from steam, powered the* Dreadnought*, which was the world's first modern battleship when it launched in 1906. He also founded the Newcastle and District Electric Lighting Company, which in 1890 opened the world's first power plant to produce electricity from steam turbines.*

*Diesel, one of the inventors of the modern automobile engine, was born in Paris in 1858, emigrated to London with his parents, and was educated in Germany. His first paper on the engine that would bear his name was published in 1893. Twenty years later he met a mysterious and sensational end when he vanished from the ocean liner* Dresden*. His body was later found floating in the North Sea; his death was presumed a suicide but has fed rumors of murder ever since.*

*Smil, a Canadian scientist and author, has written extensively about the energy economy.*

**You sometimes say that in the future the world will need more—not less—energy, in part to raise living standards in many parts of the world. That's really the key to the challenge, no? We have to break the close connection between economic growth and carbon emissions in a time of climate change.**

That's right. If you take my equation and look at the first three factors, P is going to go up by about 1.2, S is going to go up by about a factor of 2, and E, assuming lots of breakthroughs—well, we'll be generous and say that's 0.6. So basically, when you summarize the equation, it suggests that C must be about zero.

**When must C be zero?**

If you allow poor countries and the land-use sector, including livestock, to continue to have non-zero emissions, then rich countries need to be net zero by 2050, if you really want just two degrees of warming.

**If poor countries and agriculture emit significant carbon for the foreseeable future, how can the entire globe achieve net-zero emissions by the end of the century?**

Well, there are scenarios that show rich countries having negative carbon dioxide emissions in the years beyond 2050.

**You've noted that the energy industry spends 0.23 percent of revenues on research and development, compared to 20 percent for pharma and 15 percent for IT, and you blame the long lag between invention and impact in energy on those paltry investments. Is there any way to change that?**

You can look at history and ask yourself, "Who do you think were the greatest energy innovators of all time?" I think Charles Algernon Parsons [the inventor of the steam turbine] was really incredible. I think Rudolf Diesel [the inventor of the diesel engine] was also incredible. Go and look at how much money they or the company they worked for made. Diesel committed suicide because he thought he was going bankrupt. Parsons made basically nothing. During the first 20 years after you invent a new energy technology, as [Vaclav] Smil likes to remind us, the deployment that takes place, with very, very few exceptions, is quite modest. So the incentive for the inventor is most reduced where the adoption cycles are greater than 20 years. We don't have a similar situation in IT. We don't have that even in health care, although they sometimes complain that the 20 years don't give them enough time.

**A more than 20-year investment cycle seems an awfully long time. Therefore, does energy need a model for innovation different from those that have driven other technologies?**

For a lot of energy innovations, you've got to give government credit. With nuclear energy, all the key research was done either by the government or by government funding. With fossil fuels, there was clearly some spillover effect from the digital revolution to analyze geological data, but it was government investing that helped to get to this incredibly precise horizontal drilling capability. So basic R&D spending has been the thing that has driven most of the breakthroughs. We do need private-sector risk-takers to go out and scale the stuff up, which is why we paired the idea that 20 leading countries must double their energy R&D over the next five years with a group of investors [the Breakthrough Energy Coalition] that will take on funding high-risk, breakthrough companies.

**When we spoke about energy in 2010, you reminded me that the total U.S. government investment in energy R&D was around $5 billion, about 10 percent of the money it spends on defense-related research. That's not changed much in the last six years. If the government did double its investment in energy R&D, where would you want that money to be spent—on more fundamental research or on supporting the scaling up of new technologies?**

0

*Net developed-world carbon emissions needed by 2050 to avoid catastrophic climate change*

No, I'd spend it all on fundamental research. There's some really exciting materials science problems which if you solved them would have benefits far beyond the energy sector, but where you could justify the increased investment just by what it would do to improve energy innovation. For instance, the wind guys need really strong materials, and they need really good magnets. And if we can do solar chemical, and somebody figures out how to take the production of photons to hydrocarbons and scale that up by a factor of a hundred so that it becomes eco-

nomic, that's pretty miraculous, because you're creating a liquid hydrocarbon that a lot of our infrastructure, including transport, knows how to deal with today. You'd not be switching out everything except the actually primary generation piece.

Now, I don't have a pure mapping of how much you spend on R&D to how quickly you get the breakthrough. As with cancer research, there's a lot of uncertainty as to what scientific possibilities are out there. We don't have a good equation. You know, it's possible there's some guy in a laboratory today who's inventing something miraculous, but because of climate change and the value of having cheaper energy, we shouldn't just sit around and hope for his miracle; we should tilt the odds in our favor by doubling the R&D budget.

> "It's possible there's some guy in a laboratory today who's inventing something miraculous."

**It's striking that all of your examples have to do with chemistry and materials science. That's not a coincidence, is it?**

No. Take TerraPower, the nuclear fission company that I'm very involved with [along with former Microsoft chief technology officer Nathan Myhrvold]: all our biggest challenges have been in materials science. We have very high neutron bombardment of our steel plating, and the toughest engineering problem to solve has been proving that over long periods of time we don't have degradation. But the ability to model materials comes up in almost all energy breakthroughs.

**How do you respond to the argument that commercializing inventions like solar paint would take far too long to meet the time line of net-zero carbon emissions by 2050? How do you answer the thesis that to avert the worst impacts of climate change, we must deploy the clean technologies we have, while simultaneously investing in more fundamental breakthroughs as well?**

For countries that are quite wealthy, like Europe and the United States, we could bear to have energy costs go up even a factor of two in deploying what we have today. It would be a huge political trade-off, and I don't know if countries would choose to do it, but you wouldn't be impoverishing anybody.

But look at a country like India, which is paradigmatic and numerically very significant in terms of its expected additions to hydrocarbon use over the next 30 years. If you give Indians the dilemma of electrifying their country using coal or meeting a greenhouse-gas constraint that would dramatically reduce how much electrification gets done, you give them a very tough trade-off. They will ask, "Shouldn't we save millions of lives? Shouldn't we give women electric stoves instead of burning wood? Shouldn't we avoid the environmental degradation all that wood gathering involves, and all the time it demands?" I can't predict, but I imagine they'll lean toward electrifying the country, which will mean a global-scale experiment with high carbon dioxide.

So if it wasn't for technological innovation, I wouldn't be very optimistic about reducing greenhouse-gas emissions. But if we have the innovations, then we can say to India, "You can achieve two goals: you can be a great global citizen by not emitting into the atmosphere as much carbon dioxide per person as the rich nations emitted to fuel their growth, and you can electrify your country."

**Won't progress also require smart policies, including some kind of price on carbon? Wouldn't we need a carbon tax to help create a business rationale for investing more in clean technologies?**

The innovations will need to be encouraged on the supply side and demand side. The supply side is about funding basic government research, and then creating startup companies with that research.

On the demand side, there are arguments to be had about how much we ought to do and what the structure should look like, but if you look at the rich countries as a whole, they have done a lot. [In the United States] there have been things like the PTC [renewable-energy Production Tax Credit], the ITC [Investment

*The effort to generate a fuel using sunlight and a series of chemical reactions, also known as artificial photosynthesis, is the object of a multidecade R&D effort that has consumed hundreds of millions of dollars.*

*TerraPower is a spinoff of Intellectual Ventures, the technology investment firm founded by Myhrvold. Gates is both a primary investor in and a vocal champion of the company, which seeks to build advanced "traveling wave" nuclear reactors.*

*Chemist Nathan Lewis, a solar expert at Caltech, is among the researchers trying to devise titanium dioxide nanotubes that could convert sunlight into electricity. Titanium dioxide is a common component of paint. Commercial applications are probably decades away.*

*Renewable portfolio standards are state-level mandates to increase renewable electricity generation. The Obama administration's Clean Power Plan, which was placed on hold by the Supreme Court in February, would effectively act as a nationwide renewable portfolio standard.*

*Launched at the Paris climate talks last December, the Mission Innovation program calls for 20 countries, including the U.S., to double their R&D spending on clean energy over the next five years.*

*Many economists believe that a direct tax on carbon emissions is a simpler and more efficient way to reduce carbon pollution than cap-and-trade systems, which establish an upper limit on emissions and allow companies to buy and sell emissions allowances.*

Tax Credit], or the renewable portfolio standards. Now, the policies may have been too specific to particular technologies, and maybe they should be done with a more general mechanism, but overall, if you look at the relative investment in the demand side for innovation versus how much these countries have put into the supply side, it's a stunning picture. On the demand side, rich nations have invested literally hundreds of billions, but on the supply side, if you put aside China, nobody's really substantially increased their energy R&D budget over these last 15 years.

The answer to your question is: yes, we need lots of work on the demand side. But when you click on the supply side and see what we've done you'd be very disappointed, even though, in terms of billions of dollars needed, it's not nearly as much. It's surprising how little's been done.

> "Even though the Paris thing was a big step forward, there is so much work to be done in each country."

**I understand you prefer to discuss the supply side. But do you have policy preferences about how to impose a price on carbon? Do you favor a clean, transparent tax? Or would you like some kind of cap and trade? Perhaps, most plausibly, a mixture of smart policies? Or do you not care?**

Some countries will do a pure carbon tax, and there's a certain beauty to doing it that way, but the consensus that I think people will reach here in the U.S. will be to focus more on supply side.

**Then let's talk about the supply side! What is the Breakthrough Energy Coalition, and how will you decide where to invest?**

Last November, 26 wealthy individuals and myself [as well as institutions, such as the University of California] committed to invest in breakthrough energy companies. There are two ways that the coalition will make those investments. First, we'll create a special fund called Breakthrough Energy Partners that the individuals in that group will invest in, although sometimes these individuals will invest directly in companies. Second, we'll get another set of institutional investors, including university endowments, foundation endowments, and corporation funds, and try to get about an equal amount of money as we're getting from individuals for a fund for institutions, about two billion dollars.

By this summer, we'll have some of the key people and will have pulled together the investment documents, and then we'll be able to go to not only individuals who are willing to commit based on knowing me and trusting this thing would be structured well, but also the institutions.

**The coalition launched with a remarkable group of rich individuals. But I didn't see many names from the energy industry. Don't you need the expertise of the energy industry, as well as its financial resources?**

We haven't been out soliciting. But yes, if we can get people who are in today's energy market, either equipment or utilities, it would be great to have them as well. Our basic goal is that if we can raise a couple billion, we can back a lot of great companies and back them much further than a typical venture fund would choose to do.

**$5 BILLION**
*Annual amount the U.S. invests in clean-energy R&D, about 10 percent of the amount going to defense research*

**You've said you were willing to invest up to one billion dollars of your own money over the next five years. Why not invest more?**

I wish just writing a bigger check was the solution. I'll be fascinated as we get this fund together how quickly we'll be able to invest. If we can effectively invest the first couple of billion dollars, then absolutely—not only will I put more money in, but I'll call up the institutions and individuals and say, "Hallelujah, they found enough companies that now we are financially limited; we want more money."

Clean tech so far is somewhat out of favor [for investment] because people were unrealistic about how quickly some of these advances could be created. The difficulty of new adoption, of reliability, of scaling things up—all those

things—is very, very daunting. So we need to get people excited about these types of investments again, but also really have them understand that the IT world created a model in terms of time frame, patience, and even the amount of capital required that doesn't exist in the energy sector in most cases.

**Have you funded carbon capture?**
I'm an investor in David Keith's company, called Carbon Engineering, a free-air capture technology. They're building a plant. It will have costs on the order of a hundred dollars or more per ton of carbon dioxide that's pulled out with free-air capture, but having built the first plant, they'll see opportunities to bring that down.

**$1 BILLION**
*Amount Gates has pledged to contribute to clean-energy R&D over the next five years*

**How is TerraPower progressing? When will there be a commercial reactor, and why was China the only possibility for a test facility?**
They're not the only possibility. There are countries like India, Korea, Japan, France, and the U.S. that have done advanced nuclear stuff, but today about half of all the nuclear plants being built in the world are being built in China, and China's ability to do engineering is very impressive. It's likely China is where TerraPower's pilot plant will be built. In the best case, if that plant gets done by 2024, then sometime in the 2030s you'd have a design that you'd hope all new nuclear builds would adopt, because the economics, safety, waste, and all the key parameters are dramatically improved.

**Have you made any mistakes in your energy investments that you'd care to talk about?**
I'm in five battery companies, and five out of five are having a tough time. For instance, Don Sadoway's company, Ambri, is great, but they're having a real challenge in terms of getting the seals of their sodium batteries to work, and getting the economics of their batteries so that storage people would find them attractive. I don't regret having invested, but all the battery things I'm in are finding both the size of the market and proving the technology more difficult than they expected. They're still in business, but it's proving to be quite daunting. When people think about energy solutions, you can't assume there will be a storage miracle. It's still possible there will be, but we need to invest in lots of paths that don't demand storage.

**If there's no storage technology that scales, how will solar and wind ever meaningfully contribute to electricity generation?**
If you said to me, "There will be no storage miracle"—nothing like solar chemical or anything like that—then I think the likely system for a rich country looks like a gigantic high-voltage DC grid with solar and wind, and natural-gas peakers with some very high degree of carbon capture and sequestration [CCS].

If you had a supergrid that covered all of North America, and you looked at weather models and understood wind and sun patterns, and rationally used all of your solar and wind to maximize diversity, then with a magic, continent-wide grid, with huge capacity that is doable with the right government approvals, you'd end up probably being able to cover about 80 percent of energy needs. For the remaining 20 percent, you could, in the worst case, use natural-gas peakers and CCS. It's a little bit easier to do CCS in a natural-gas plant than it is in a coal plant, and it's easier to do it for 20 percent of the energy than it is for all of the energy.

The grid's there, and it's the most likely solution that's straightforward. Doing a big high-voltage DC grid is quite economic. It's only magic in the sense that the sovereign has to clear the right-of-ways and create the right economic incentives. It's not a technology miracle; it's a policy miracle.

**Can the U.S., which committed to reducing its emissions by more than 25 percent by 2025, and other countries meet their obligations under the Paris agreement?**
Even though the Paris thing was a big step forward, there is so much work to be done in each country. I think people can be skeptical about how many countries will meet their commitments and, even if those commitments are met, how they will be met. Take, for example, the U.S. commitment: a lot of the way the U.S. is meeting its commitments is by shifting the relative energy mix toward natural gas.

If we didn't have innovation, if you said "Hey, science is frozen, we just have today's technology," I would be quite pessimistic about the world [avoiding] even ... a three-degree scenario. The reason I'm optimistic about climate change is because of the potential for innovations where C equals zero.

*Carbon Engineering is one of several companies, including the Swiss firm Climeworks, working on systems to capture carbon from the air. While these technologies have been touted as having the potential to significantly reduce the total amount of carbon in the atmosphere, for now that's a pipe dream.*

*In September 2015, TerraPower signed a deal with China National Nuclear Corporation to build a prototype traveling-wave reactor in China. China has several other programs to develop advanced reactors, including a controversial collaboration between the U.S. Department of Energy and the Chinese Academy of Sciences to build a prototype designed to run on thorium, a radioactive element that is cleaner, safer, and more abundant than uranium.*

*Considered one of the most promising startups working on new types of grid-scale batteries, Ambri revealed disappointing test results for its technology last September, forcing it to push back commercial deployment indefinitely.*

# The People's Robots

## Can China reboot its manufacturing industry—and the global economy—by replacing millions of workers with machines?

By Will Knight
Photos by Daniele Mattioli

Inside a large, windowless room in an electronics factory in south Shanghai, about 15 workers are eyeing a small robot arm with frustration. Near the end of the production line where optical networking equipment is being packed into boxes for shipping, the robot sits motionless.

"The system is down," explains Nie Juan, a woman in her early 20s who is responsible for quality control. Her team has been testing the robot for the past week. The machine is meant to place stickers on the boxes containing new routers, and it seemed to have mastered the task quite nicely. But then it suddenly stopped

*A robot arm moves circuit boards around for testing inside CIG's factory in Shanghai. Previously the work was done by hand.*

MIT TECHNOLOGY REVIEW
VOL. 119 | NO. 3

working. "The robot does save labor," Nie tells me, her brow furrowed, "but it is difficult to maintain."

The hitch reflects a much bigger technological challenge facing China's manufacturers today. Wages in Shanghai have more than doubled in the past seven years, and the company that owns the factory, Cambridge Industries Group, faces fierce competition from increasingly high-tech operations in Germany, Japan, and the United States. To address both of these problems, CIG wants to replace two-thirds of its 3,000 workers with machines this year. Within a few more years, it wants the operation to be almost entirely automated, creating a so-called "dark factory." The idea is that with so few people around, you could switch the lights off and leave the place to the machines.

But as the idle robot arm on CIG's packaging line suggests, replacing humans with machines is not an easy task. Most industrial robots have to be extensively programmed, and they will perform a job properly only if everything is positioned just so. Much of the production work done in Chinese factories requires dexterity, flexibility, and common sense. If a box comes down the line at an odd angle, for instance, a worker has to adjust his or her hand before affixing the label. A few hours later, the same worker might be tasked with affixing a new label to a different kind of box. And the following day he or she might be moved to another part of the line entirely.

Despite the huge challenges, countless manufacturers in China are planning to transform their production processes using robotics and automation at an unprecedented scale. In some ways, they don't really have a choice. Human labor in China is no longer as cheap as it once was, especially compared with labor in rival manufacturing hubs growing quickly in Asia. In Vietnam, Thailand, and Indonesia, factory wages can be less than a third of what they are in the urban centers of China. One solution, many manufacturers—and government officials—believe, is to replace human workers with machines.

The results of this effort will be felt globally. Almost a quarter of the world's products are made in China today. If China can use robots and other advanced technologies to retool types of production never before automated, that might turn the country, now the world's sweatshop, into a hub of high-tech innovation. Less clear, however, is how that would affect the millions of workers recruited to China's booming factories.

There are still plenty of workers around now as I tour CIG's factory with the company's CEO, Gerald Wong, a compact man who earned degrees from MIT in the 1980s. We watch a team of people performing delicate soldering on circuit boards, and another group clicking circuit boards into plastic casings. Wong stops to demonstrate a task that is proving especially hard to automate: attaching a flexible wire to a circuit board. "It's always curled differently," he says with annoyance.

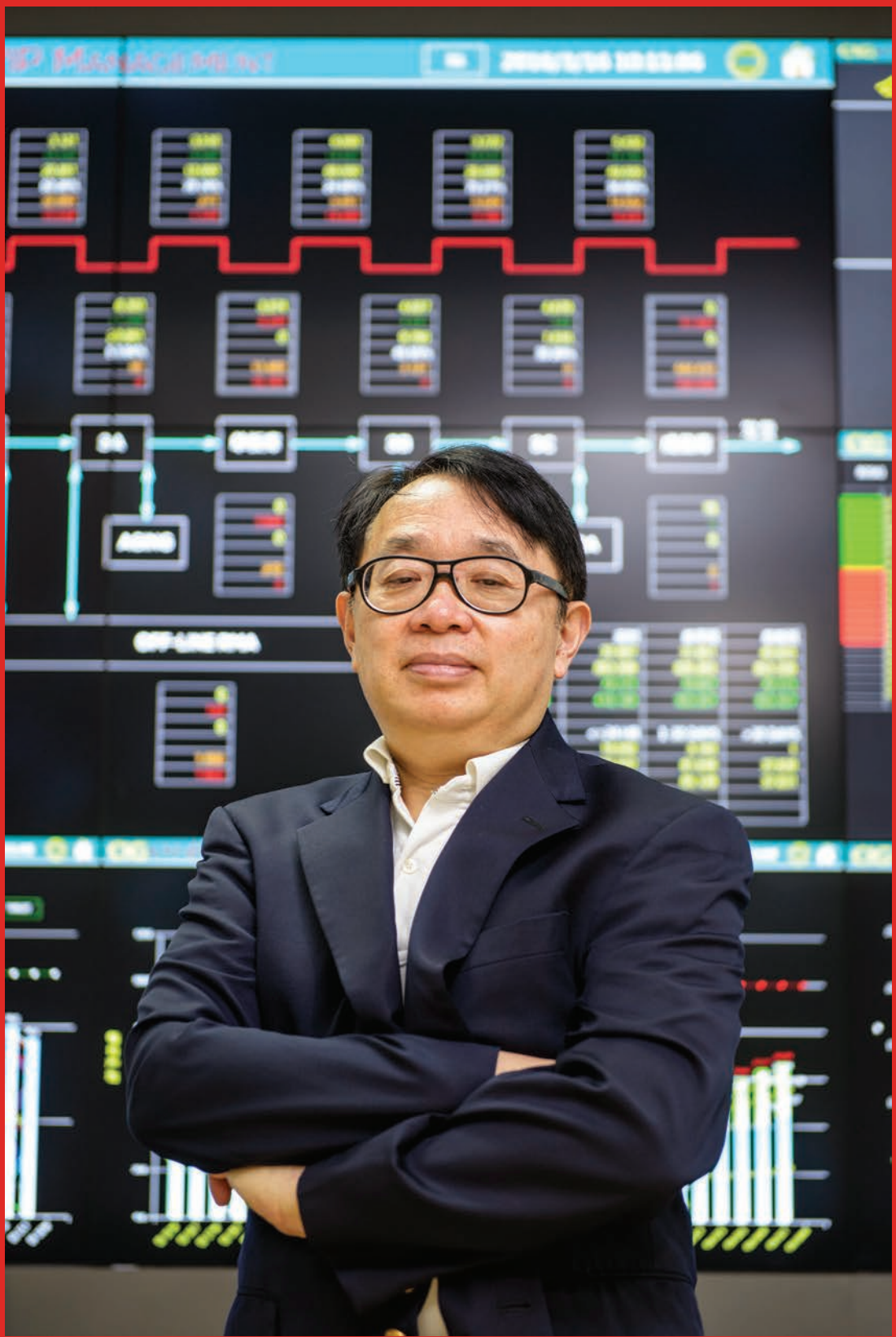
But there are some impressive examples of automation creeping through Wong's factory, too. As we walk by a row of machines that stamp chips into circuit boards, a wheeled robot roughly the size of a mini-fridge rolls by ferrying components in the other direction. Wong steps in front of the machine to show me how it will detect him and stop. In another part of the factory, we watch a robot arm grab finished circuit boards from a conveyor belt and place them into a machine that automatically checks their software. Wong explains that his company is testing a robot that does the soldering work we saw earlier more quickly and reliably than a person.

**Within a few years, CIG plans to have a largely automated operation—what's sometimes called a "dark factory."**

After we finish the tour, he says, "It is very clear in China: people will either go into automation or they will go out of the manufacturing business."

## Automate or bust

China's economic miracle is directly attributable to its manufacturing industry. Approximately 100 million people are employed in manufacturing in China (in the U.S., the number is around 12 million), and the sector accounts for almost 36 percent of China's gross domestic product. During the last few decades, manufacturing empires were forged around the Yangtze River Delta, Bohai Bay outside Beijing, and the Pearl River Delta in the south. Millions of low-skilled migrant workers found employment in gigantic factories, producing an unimaginable range of products, from socks to servers. China accounted for just 3 percent of global manufacturing output in 1990. Today it produces almost a quarter, including 80 percent of all air conditioners, 71 percent of all mobile phones, and 63 percent of the



*Gerald Wong, CEO of CIG, is developing an automated electronics factory.*


*Workers at CIG retrieve items from one of several mobile robots that ferry materials around the facility.*

world's shoes. For consumers around the world, this manufacturing boom has meant many low-cost products, from affordable iPhones to flat-screen televisions.

In recent years, though, China's manufacturing engine has started to stall. Wages have increased at a crippling 12 percent per year on average since 2001. Chinese exports fell last year for the first time since the financial crisis of 2009. And toward the end of 2015 the Caixin Purchasing Managers' Index, a widely used indicator of manufacturing activity, showed that the sector had contracted for the 10th month in a row. Just as China's manufacturing boom fed the global economy, the prospect of its decline has already started to spook the world's financial markets.

Automation appears to offer an enticing technological solution. China already imports a huge number of industrial robots, but the country lags far behind competitors in the ratio of robots to workers. In South Korea, for instance, there are 478 robots per 10,000 workers; in Japan the figure is 315; in Germany, 292; in the United States it is 164. In China that number is only 36.

The Chinese government is keen to change this. On March 16, officials approved the latest Five Year Plan for China's economy, which is reported to include an initiative that will make billions of yuan available for manufacturers to upgrade to technologies including advanced machinery and robots. The government also plans to create dozens of innovation centers across the country to showcase advanced manufacturing technologies. Some regional authorities in China have been especially bold in their own efforts. Last year the government of Guangdong, a province that contains many large manufacturing operations, promised to spend $150 billion equipping factories with industrial robots and creating two new centers dedicated to advanced automation.

The goal is to overtake Germany, Japan, and the United States in terms of manufacturing sophistication by 2049, the 100th anniversary of the founding of the People's Republic of China. To make that happen, the government needs Chinese manufacturers to adopt robots by the millions. It also wants Chinese companies to start producing more of these robots. The hope is that this will create a virtuous cycle, helping to birth a new high-tech industry and inspiring innovations that could spill over from manufacturing into other sectors and products.

Introducing hordes of robot workers is hardly something that can be done overnight, however. That much is clear from the struggles faced by Foxconn, a $130 billion Taiwanese manufacturer famous for employing hundreds of thousands of workers in city-size factories—and for making, among other products, Apple's iPhones. In 2011, Foxconn's founder and

CEO, Terry Gou, said he expected to have a million robots in his company's plants by 2014. Three years later, the effort had proved more challenging than expected, and just a few tens of thousands of robots had been deployed.

Despite the challenges, Day Chia-peng, general manager of Foxconn's automation technology development committee, says the company is automating a growing number of tasks on its lines. These include the manufacture of displays and printed circuit boards, although processes that involve bending

The transition to robot workers may upend Chinese society, since so many people work in manufacturing.

or snapping components into place still pose challenges. The company is even exploring ways that products themselves can be redesigned to make automated manufacturing easier. And it recently said it will sell some of the robots it has developed in-house to other manufacturers.

The transition from human to robot workers may upend Chinese society. Some displaced factory workers could find employment in the service sector, but not all of the 100 million now employed in factories will find such jobs a good match. So a sudden shift toward robots and automation could cause economic hardship and social unrest. "You can make the argument that robotic technology is the way to save manufacturing in China," says Yasheng Huang, a professor at MIT's Sloan School of Management. "But China also has a huge labor force. What are you going to do with them?"

## Dancing bots

A few days before visiting CIG, I went to China's first major robotics event, the World Robot Conference, held inside a vast exhibition hall located within Beijing's Olympic Park. The city was in the grip of an unusually cold spell, and producing the electricity to meet its heating needs had resulted in lung-searing air pollution from nearby coal power plants. But the snow and smog had done nothing to deter hundreds of researchers and companies, and thousands of attendees, from coming to the event.

First came a theatrical opening ceremony, during which a huge video wall showed innovations from China's ancient history spliced, somewhat oddly, with clips of robots from science fiction movies. The guest list included several high-ranking Chinese politicians. Li Yuanchao, China's vice president, read messages of congratulations from President Xi Jinping and Premier Li Keqiang. The vice president said that investing in robotics research would not only feed the country's manufacturing industry but encourage greater domestic innovation.

After watching several talks, I wandered past endless demos set up by robot companies and research institutes. I watched as an enormous industrial robot fitted with a fork-like appendage went through some sort of routine factory work at terrifying speed. Other demos were more whimsical, like a small industrial machine performing a mesmerizing rendition of a traditional Chinese dragon dance (in full costume), and a mobile robot equipped with two racquets playing badminton with excited attendees. A humanoid robot with flashing eyes was carrying a small automated vacuum cleaner around on a tray.

It was also possible to grasp just how ambitious China will be in trying to replace human workers in its factories. HIT Robot Group, a company affiliated with one of the country's foremost technical universities, Harbin Institute of Technology, had mocked up a battery production line that itself seemed like one giant robot. Robotic vehicles ferried components between various manufacturing machines. The only spots for humans were inside a control room in the center and on a line where especially fiddly manual work needed to be done. I later learned that HIT estimates the new factory could reduce human labor by as much as 85 percent.

But it was also evident that as a country with a history of seemingly endless cheap labor, China had to date been outpaced in the robot revolution. Rethink Robotics, a Boston-based company, was showing off a pair of flexible and intelligent industrial machines. Unlike conventional industrial robots, these products, called Baxter and Sawyer, require very little programming, and they are equipped with sensors that allow them to recognize objects and avoid hitting people. They also cost between $20,000 and $30,000 instead of the hundreds of thousands typical of an industrial robot. Speaking to me after the event, Rethink founder and robotics pioneer Rodney Brooks said that China represents a huge potential market for his company, which recently opened offices in Shanghai. Chinese robot makers are likely to start making more flexible and intelligent robots, too. But for now their products lag behind those of Western manufacturers.

*A CIG worker inspects a custom-made machine for building circuit boards.*

*Researchers at Shanghai Jiao Tong University are developing humanoid and walking robots.*

MIT TECHNOLOGY REVIEW
VOL. 119 | NO. 3

"A game we often play when we go to a trade show in the Far East is we go and see the industrial robots from little companies and say, 'Oh, that's a copy of that, and that's a copy of that,'" Brooks said. It will, he suggested, take time for China's robotics companies to catch up.

## Reinvented in China

To see for myself how far China's researchers have to go, I visited Shanghai Jiao Tong University, one of the country's most prestigious institutions and home to China's oldest academic robotics lab, founded in 1979. I found myself on a lush and sprawling campus in a quiet suburb in south Shanghai, surrounded by students cycling around on squeaky bicycles. There, I found a modern-looking building that housed the robotics lab.

Zhu Xiangyang, a professor in his late 40s with thin glasses and a fleece sweater-vest, welcomed me to his office with tea and an irrepressible smile. The lab has a few dozen professors and research scientists and more than 100 doctoral and master's students, and Zhu is justifiably proud of its research. In one room was a brain-controlled robotic wheelchair, operated by means of an electroencephalogram cap worn by a graduate student. A video showed a cyborg cockroach fitted with a wireless implant that connected to its peripheral nervous system and made it possible to control the creature's movements from a computer. In another room, a researcher demonstrated snake-like and soft-bodied robots capable of reaching or crawling through narrow spaces. Inside a garage, a prototype self-driving car, not unlike one of Google's, is being developed in collaboration with a Chinese carmaker called Chery.

Despite the impressive research projects at places like Jiao Tong, I kept wondering just how China will fulfill its manufacturing ambitions. Kai Yu is the founder of a startup called Horizon Robotics and was previously the head of an AI-focused research lab set up by Baidu, China's dominant Internet company. Within the Baidu lab, Yu and colleagues were focused on a field of AI called deep learning, which involves training large simulated neural networks to recognize patterns in data. Researchers are now starting to explore how machine learning might make the next generation of industrial robots even smarter and more flexible. "In the future, what I see is China being more creative [in robotics]," Yu told me. "Original design, original ideas, but also some of the fundamental technologies, like deep learning, neural networks, artificial intelligence."

Yu believes that the AI techniques developed by China's big Internet companies for search, e-commerce, and other purposes could be applied to robots. "China has a very good opportunity to catch up," he said. "The skills they have learned in the last five years can be transferred to making intelligent machines."

When I later toured CIG's factory, it wasn't too hard to imagine how such advances could start feeding into Wong's efforts to automate his operation. For one thing, a robot capable of learning and adapting presumably wouldn't be baffled by a misaligned box that needs labeling.

After the tour, Wong took me through a PowerPoint presentation that laid out the company's plan for the next few years, and then the conversation turned to intelligent robotics. "We're going to use standard robots at first," Wong said. "But then we're going to use more advanced ones. More and more, we need to get into more advanced robotics. That can help make a dark factory."

> "More and more, we need to get into more advanced robots. That can help make a dark factory."

Given the economic imperative, the government's determination, and the country's growing technological sophistication, it seems very likely that manufacturing companies across China will automate successfully and that the country will become a leader in the technologies of advanced automation.

And yet it's strange to think about the changes in store for Chinese manufacturing workers. At one point during our tour we had passed a group of about 20 people taking an afternoon break. Everyone was apparently snoozing, heads rested on arms folded in front of them. That's hardly something a robot needs to do. But I couldn't help wondering what will happen to these workers once robots have taken their jobs. Wong says they will most likely return to their hometowns and find employment there, on a farm or perhaps in a shop or restaurant. That may be so, but for some it won't be so simple.

A week after leaving China, I received an e-mail from Wong with some more information about his plans, along with a characteristically bold promise. "Stay in touch," he wrote. "We will make the dark factory happen."

*Will Knight is* MIT Technology Review*'s senior editor for AI.*

# The Extinction Invention

A genetic technology that can kill off mosquito species could eradicate malaria. But is it too risky to ever use?

By Antonio Regalado

JENNIFER DANIEL

Malaria kills half a million people each year, mostly children in tropical Africa. The price tag for eradicating the disease is estimated at more than $100 billion over 15 years. To do it, you'd need bed nets for everyone, tens of thousands of crates of antimalaria drugs, and millions of gallons of insecticides. But it would take more than stuff. You'd need things the poorest countries in the world don't have, like strong governments, purchasing power, and functioning public health systems. So malaria keeps killing.

But what if, instead, you needed only a bucket full of mosquitoes?

I saw such an invention at Imperial College London. A student led me through a steel door, under a powerful gust of air, and into a humid room heated to 83 °F. Behind glass, mosquitoes clung to the sides of small cages covered in white netting. A warning sign read, "THIS CUBICLE HOUSES GENE DRIVE GM MOSQUITOES." It went on to caution that the insects' DNA contains a genetic element that has "a capacity to spread" at a "disproportionately high" rate.

A gene drive is an artificial "selfish" gene capable of forcing itself into 99 percent of an organism's offspring instead of the usual half. And because this particular gene causes female mosquitoes to become sterile, within about 11 generations—or in about one year—its spread would doom any population of mosquitoes. If released into the field, the technology could bring about the extinction of malaria mosquitoes and, possibly, cease transmission of the disease.

The mosquitoes I saw were created as part of Target Malaria, a project led by Imperial College that has quietly expanded to involve 16 institutions and includes teams in Italy and three African countries, Mali, Burkina Faso, and Uganda, where secure mosquito facilities are currently being outfitted. Its work is funded by the health foundation of Microsoft billionaire Bill Gates, in Seattle. An official there said the foundation now considers gene drives "necessary" to end malaria and projects that the technology will be ready years before an effective vaccine. According to a business plan developed for the Gates Foundation, the self-annihilating mosquitoes could be unleashed in 2029.

The plan is to disperse *Anopheles gambiae* mosquitoes harboring selfish genes across sub-Saharan Africa. The gene drive could spread across a huge swath of territory, causing mosquitoes to disappear and blocking transmission of the parasite that causes malaria. "Malaria is a problem of poverty, of instability and lack of political will," says Andrea Crisanti, the Italian parasitologist and genetic engineer who developed the insects at Imperial College. "We are asking the drive to do what we can't do politically or economically."

Beyond helping with malaria, conservationists think gene-drive technology could save Hawaii's disappearing native birds (from avian malaria) or maybe rid Australia of invasive, destructive toads that have been hopping westward across the continent. Why not also eliminate *Aedes aegypti*, the mosquito spreading dengue fever and Zika in the Americas?

The technology creates risks that society has never before had to consider. Would removing mosquitoes upset ecosystems? Are we risking a genetic epidemic if the selfish DNA should jump the species barrier to affect other insects? Most perplexing: what country, agency, or individual has the right to change nature in ways that could affect the entire globe? "This is why I hate the malaria problem," says Kevin Esvelt, an MIT biologist who has been warning about the unprecedented dilemmas gene drives will create. "It makes the technology so tempting to use."

These questions need answers soon. Only 12 months ago, gene-drive technology was still a promising theory. Not anymore. Rapid-fire technical advances are occurring thanks to CRISPR, a new gene-editing technique. At Imperial's lab I peered through a microscope at an immature mosquito, called a pupa, a grisly creature that looks like a holiday ham with a lobster tail attached. Inside its body I could see fiery fluorescent spots where an artificial selfish gene was busy copying itself. The potentially ecosystem-altering transformations had been carried out mostly by a 27-year-old student named Andrew Hammond during a few months of late nights in the lab. "There are so many cool ways to build these," Hammond exulted. "There are so many easy things to do."

And that's just the problem. Officials in the United States and elsewhere worry that it might be a little too easy. The FBI is looking into whether gene drives could be misused, say, to create a designer plague. And this May, the U.S. National Academy of Sciences is expected to publish recommendations for "reducing ecological and other risks" ahead of any field test. Twenty-seven researchers wrote to *Science* with warnings against the accidental release of gene-drive organisms, something they fear would devastate public trust. Others have said the research ought to be classified, though it's too late for that.

**Despised species**

Of the 3,500 species of mosquitoes, about 30 spread malaria, although three nearly indistinguishable subtypes of *Anopheles gambiae* do the most damage in Africa. The female mosquito's bite spreads the plasmodium parasite, which gives people fever and chills by exploding red blood cells. These three mosquitoes are the ones targeted by Imperial for elimination, Crisanti says, swinging his glasses by a tip and jumping up from his chair.

Crisanti acknowledges that gene-drive technology is generating tension. Pres-


*Room-size insect cages in Perugia, Italy, mimic the outdoors. Here researchers can study the mating behavior of self-destructing mosquitoes (opposite page).*

MICHELE BORZONI

sure will mount to use the technique, given the health and social benefits that ending malaria could bring. On the other hand, there are as yet no agreed-upon regulations or procedures for developing a technology able to spread itself among wild organisms. "The gene drive is controversial for the potential to wipe out a species," he says. "So there should be a clear benefit."

A gene drive wouldn't necessarily doom these mosquito species to extinction. Pockets of mosquitoes might remain, or they could be maintained in a lab, should anyone want to bring them back. But eradication is a possible outcome, Crisanti says, in particular if release of the gene drive coincided with conditions like a dry spell or a cold snap. Species go extinct continually, of course, but I wondered: is it ethical to eliminate any part of nature on purpose? "Are you asking in a Darwinian way or a theological way?" Crisanti responded. "I think it's a species competition between us and the mosquito. And I don't think a species has the right to exist or not to exist." He says what species do have is "fitness"—they have adapted to flourish in their environmental niche. For species we hope to save, we might use gene drives to add beneficial genes, like ones for disease resistance. For species we despise, we can add ones that make them unfit for survival.

**Selfish genes**

Target Malaria is led by Austin Burt, an evolutionary theorist at Imperial College whose specialty is selfish genetic elements. These are parasitic genes, found in many species, that make extra copies of themselves. (One, called the P element, even managed to hitchhike its way into the genome of every fruit fly on Earth during the 20th century.) Burt was interested in a particular kind of selfish gene present in slime molds, called an endonuclease. These slash open DNA at very precise spots they recognize and then, by offering themselves as a repair template, can trick a cell into copying them. Burt concluded that the simplicity of this process left it "open to human artifice," and in a 2003 paper he described how it could be turned into an extinction device.

The paradox Burt had to solve is how something very bad for mosquitoes could also be spread by them. One answer, he saw, was a selfish gene that is harmless if one copy is present but causes sterility if two copies are. (Like humans, mosquitoes have two sets of chromosomes, one from each parent.) Starting with a male mosquito with one copy, the selfish gene will ensure that it ends up in every one of his sperm, rather than just half. That way any offspring with a wild mosquito will also be carriers, as will all their offspring's offspring. As a result, the gene will rocket through the population.

Eventually, it becomes likely that any mating pair of mosquitoes will both be carriers—and their offspring, with two copies, will be infertile. Quickly, the population will crash, reeling from the genetic poison. On my dog-eared copy of Burt's paper, I underlined its concluding sentences: "Clearly, the technology described here is not to be used lightly. Given the suffering caused by some species, neither is it obviously one to be ignored."

## Does any country, agency, or individual have the right to change nature in ways that could affect everyone?

Burt is a retiring Canadian whom I located in an office that was largely empty, except for a computer. He served tea that no one drank and answered several of my most provocative formulations about the massive power of biotechnology by saying, "Um, yeah." He did confide that he'd tried to patent his idea. But it was rejected because he had little experimental evidence at the time to prove it could work. "I wanted to believe I had invented something," he says.

At the time, Crisanti's lab had just determined how to genetically engineer *Anopheles* mosquitoes—a prerequisite for Burt's ideas to work. They applied to the Gates Foundation for funding, and since then Gates has spent $44 million on the project, easily the largest sum spent to date on gene-drive research.

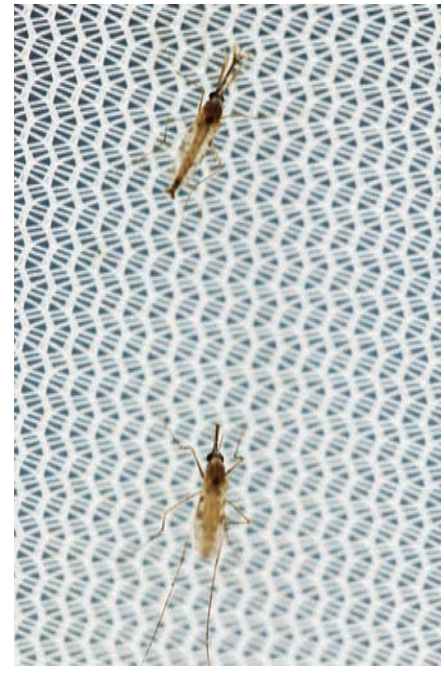
Yet engineering a selfish gene that would perform as predicted by the equations on Burt's computer screen proved difficult. Crisanti's team tried adapting selfish genes from slime molds, but it was difficult to make them cut vastly different mosquito genes. By 2011, the team had a partial prototype but nothing able to spread widely in the wild.

Then, in March of 2015, two fly biologists in California, Ethan Bier and his student Valentino Gantz, announced they'd created a selfish gene that fulfilled Burt's prophecy. It spread through a population of lab flies, causing a genetic change that turned the insects yellow. Instead of struggling with slime molds, Bier and Gantz had used Cas9, the DNA-slicing molecule becoming famous for its role in the gene-editing technology called CRISPR. The virtue of Cas9 is that it's easily directed to snip open any DNA sequence you like. So they'd added Cas9 to the fruit fly genome and told it where to cut.

This meant that with CRISPR, even a two-person team could, in theory, change an entire species. By last December, Crisanti's group and another, led by Bier and mosquito expert Anthony James, had both used CRISPR to build gene drives capable of spreading traits through mosquito populations in cages—and probably in the wild as well.

With more scientists working on gene drives, the chance of accidental release has become a concern. Had one of Bier's insects escaped into California's orchards, it could have turned all the flies yellow. In August, Burt, Bier, and 25 others wrote a letter to *Science* agreeing on the need for "stringent confinement strategies" to avoid a genetic spill and calling on scientists to refuse requests to share the organisms they have made until some kind of rules can be figured out.

Imperial's mosquito lab in London is definitely no Fort Knox, with students coming and going. Instead, a key safety measure is its location far from the current range of *Anopheles gambiae*. Any escaping mosquitoes—the students call them "fliers"—would probably get knocked senseless by dry air and cold as soon as they hit the lab hallways. And even if one somehow made it 200 yards onto Queen's Lawn, it would find no other mosquito to mate with. The mosquitoes I saw in London, in any case, are not yet ready for release. They aren't too healthy—it would be difficult for them to compete and reproduce in the wild. And in two of the cages the gene drive, which spread



rapidly at first, began disappearing after a few generations of mosquitoes. The likely reason is resistance. One or more of the mosquitoes may have developed immunity to the drive, perhaps through a chance DNA mutation, and these mosquitoes' offspring quickly multiplied.

"We have some problems to solve, but we have a lot of tricks in the cupboard," says Tony Nolan, the scientific lieutenant of Crisanti's lab. One idea is to combine several drives, targeting three different DNA sites at once. Mosquitoes might eventually evolve resistance to all three, but maybe not before they're all dead.

**Deploying the troops**

The Gates Foundation has spent $36.7 billion on education, public health, and vaccines since its inception in 2000. The fraction spent on gene drives barely registers, yet the technique has taken on a special allure in solving malaria, long one of Gates's top objectives. "If you were to invent the ideal way to tackle a problem in the developing world ... it would be a gene drive," says Fil Randazzo, a deputy director at the foundation.

If it works, it will be incredibly cheap, easy to distribute, and egalitarian, benefiting everyone, rich or poor. It will also keep working once released, avoiding a common problem: often, the most difficult part of eradicating a disease is the endgame, when attention wanders elsewhere and spending per case skyrockets. In a scenario Randazzo outlined for me, buckets of mosquitoes would be released every 50 kilometers or so, starting a chain reaction that, over two years, would flow through intervening forests and pasturelands and towns. The number of surviving mosquitoes would collapse, to less than 1 percent of normal levels. With the help of bed nets and sprays, bites would be at a minimum, breaking the cycle of malaria transmission. A campaign of drug treatment could then clear out the parasite's human reservoir—in some West African countries 25 percent of the population is infected.

The Gates Foundation has said it no longer believes that malaria can be wiped out without a gene drive. "You can't walk around with a bed net on you all the time. That's not going to eliminate malaria,"


says Randazzo. With a gene drive, "human behavior change is not required."

The Imperial team has begun building mathematical models of geography, climate, and other factors to get a handle on how a gene drive might act in the real world. In Burkina Faso, scientists have been releasing *Anopheles* doused with fluorescent dust in order to track them. Burt says he believes a drive could spread five to 20 kilometers a year from any release point, and that fewer than 500 mosquitoes could set off the reaction.

Some scientists told me they believe the malaria project is doomed. What if different mosquitoes end up transmitting the disease instead? Guy Reeves, an evolutionary biologist at Germany's Max Planck Institute, predicts that resistant insects will be the main problem, saying they'll cause the technology to fizzle. "We can't go for the shiny new thing every time," says Reeves, who thinks insects based on Burt's theories "will never prove sufficiently predictable to use with any confidence."

*At the Italian outpost of Target Malaria, female* Anopheles *mosquitoes take a blood meal (far left). Three days later they will lay eggs. On a monitor (left) a mosquito larva glows with a fluorescent trace. A lab worker (right) carries out DNA tests.*

This March, around 75 policy experts and scientists, including Burt, attended a three-day closed-door symposium on gene drives in North Carolina. People who were there say concern was palpable about the prospect of genetic changes that can spread widely, across borders. MIT's Esvelt, who attended, says the problem with the malaria idea is that it "will have an effect on everyone" in Africa but that getting everyone there to agree to the technology will be impossible. "I think Gates has every intention of pushing this forward," he says. "And the question is, how can you do it ethically?"

Randazzo says Gates's organization is committed to handing over the gene-drive technology "to the African people" and letting them decide. Efforts in this direction are well advanced. Starting in 2012, Target Malaria started developing ground operations in a handful of African countries, training scientists, refitting insect labs, and sending teams to brief local communities.

The plan resembles a military campaign, complete with drills, maneuvers, and blank charges. It includes the staged introduction of genetically modified mosquitoes that lack a gene drive. Although these won't help with malaria, local scientists can train with them and create a regulatory path for the real thing. An application to import Africa's first genetically modified mosquitoes is already pending in Burkina Faso.

But the real gene-drive insects will remain in Europe until African countries have accepted the technology and its consequences. The reason is that in a tropical location, unlike London, a lab mishap that lets mosquitoes escape could have irreversible consequences. "We won't import them to Africa until it's accepted, because we don't think we could guarantee 100 percent it will be contained," says Delphine Thizy, the political scientist who manages Target Malaria's engagement teams.

Will people in Africa want this technology? I spoke to a Kenyan entomologist, Richard Mukabana, who worked on the ground campaign in communities around Lake Victoria. Using posters and diagrams, the teams visited rural areas to explain the idea, often to people who are illiterate. One cartoon used to convey what's going on shows a blond scientist holding a mosquito cage next to a British flag. The objective of the ground work is to establish a "social license to operate"—a type of agreement, says Mukabana, that's not written down or tacked to a wall but will have to exist if a gene drive is ever to be released.

Not even most scientists yet know what a gene drive is, or how one works. And describing it to people in the Luo dialect (the language President Obama's father spoke) is challenging, since the language lacks a word for DNA. Mukabana borrowed words from English and Swahili and used "blood" as a synonym for genes.

Mukabana told me that when people in communities where children are dying from malaria hear that the disease could be eliminated, they're for it. And if there's a defender of mosquitoes around Lake Victoria, he didn't meet one. "People won't bother with mosquitoes going extinct," he says.

"It's a species competition between us and the mosquito."

*Antonio Regalado is* MIT Technology Review*'s senior editor for biomedicine.*

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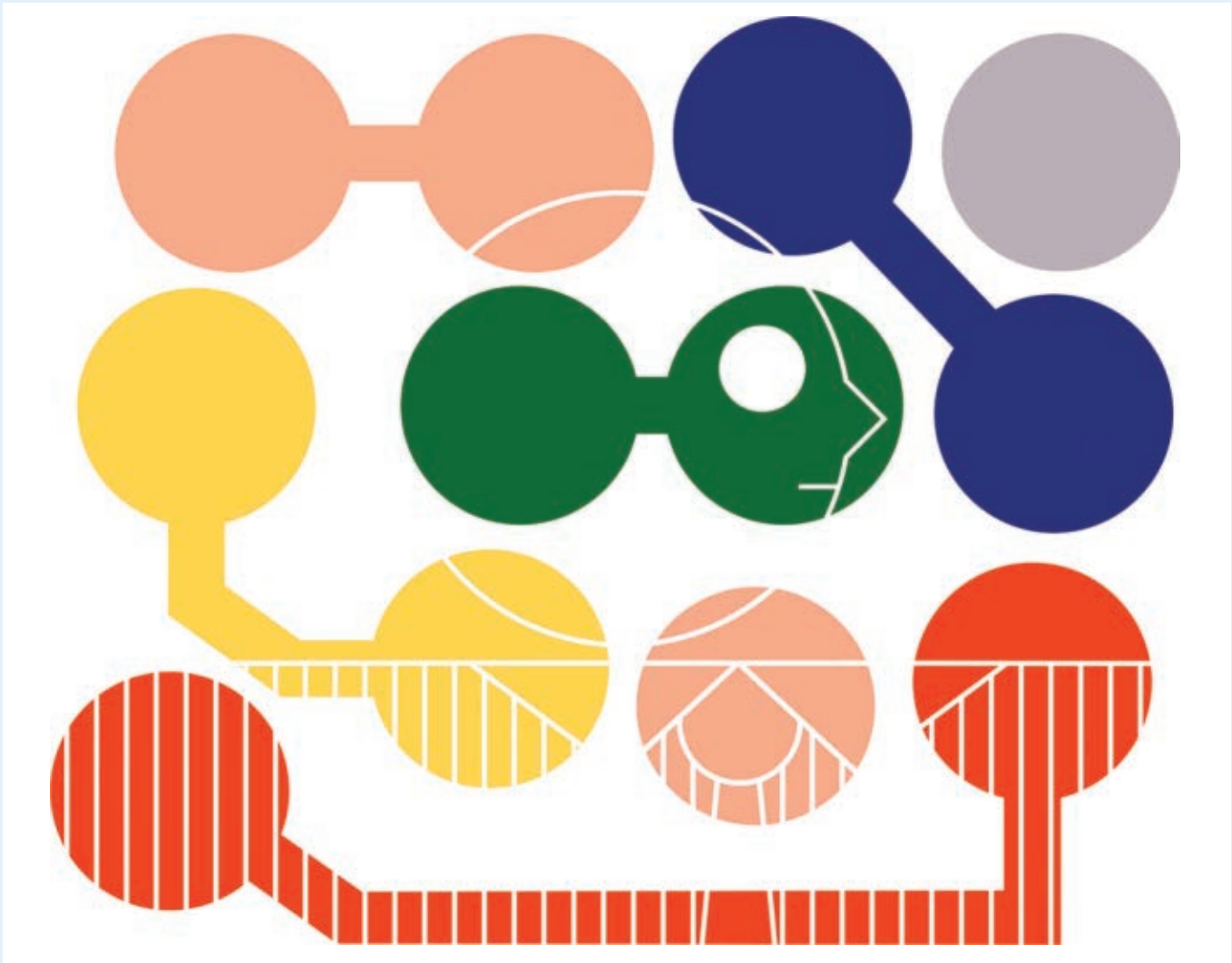
CONTENTS



# AI Takes Off

More companies are looking to artificial intelligence to change their business. Has AI's big moment finally arrived?



JAMES GRAHAM

**The Big Question**

# AI Hits the Mainstream

More industries are looking for ways to use artificial intelligence. What will that mean for the technology's future?

● For Robert Welborn, head of data science for the insurer and finance company USAA, 2015 was the year machine learning started to make commercial sense. Access to improved machine-learning tools, cheaper processing technology, and a sharp decline in the cost of storing data were key. When those developments were combined with USAA's abundance of data, a technology studied for decades suddenly seemed practical.

Insurance, finance, manufacturing, oil and gas, auto manufacturing, health care: these may not be the industries that first spring to mind when you think of artificial intelligence. But as technology companies like Google and Baidu build labs and pioneer advances in the field, a broader group of industries are beginning to investigate how AI can work for them, too.

How will AI develop as it is commercialized, and how will the technology change these diverse industries? Those are the big questions of this Business Report.

Today the industry selling AI software and services remains a small one. Dave Schubmehl, research director at IDC, calculates that sales for all companies selling cognitive software platforms—excluding companies like Google and Facebook, which do research for their own use—added up to $1 billion last year. He predicts that by 2020 that number will exceed $10 billion. Other than a few large players like IBM and Palantir Technologies, AI remains a market of startups: 2,600 companies, by Bloomberg's count.

That's because despite rapid progress in the technologies collectively known as artificial intelligence—pattern recognition, natural language processing, image recognition, and hypothesis generation, among others—there still remains a long way to go.

USAA, just one early adopter, has been testing ways to use AI to fine-tune its detection of identity theft. Its system looks for patterns that don't match a customer's typical behavior and identifies those anomalies even on the first instance, Welborn says. Traditional systems wouldn't catch a new pattern of crime until the second time it happened. "Our learning systems are really good at understanding things that look like fraud," he says.

**Improved machine-learning tools plus a drop in the costs of data storage and processing technology made 2015 a breakout year for AI.**

Another project being tested at USAA tries to improve customer service. It involves an AI technology built by Saffron, a division of Intel, using an approach designed to mimic the randomness of the connections made by the human brain. By combining 7,000 different factors, the technology can match broad patterns of customer behavior to that of specific members, and 88 percent of the time it can correctly predict things like how certain people might next contact USAA (Web? phone? e-mail?) and what products they will be looking for when they do. Without the AI, USAA's systems were guessing right 50 percent of the time. That test is now being expanded.

General Electric is using AI to improve service on its highly engineered jet engines. By combining a form of AI called computer vision (originally devel-

## What Is AI?

**It has grown up out of many different disciplines and has many definitions. Here is ours.**

Artificial intelligence, as we use the term in this report, is an evolving constellation of technologies that enable computers to simulate elements of human thinking—learning and reasoning among them. Regular improvements in Google's search algorithm, for example, come from machine learning, a type of AI that programs systems to learn from data, find patterns in it, and make predictions about it. The same technology has been pivotal to voice and image recognition as well as advances in self-driving cars. Integral to many recent improvements in the field is a form of machine learning called deep learning. Loosely modeled on the way neurons and synapses in the brain change as they are exposed to new input, it has been used independently or in combination with other AI approaches to help machines tackle tricky tasks and exhibit something resembling intuition, in some cases performing tasks better than humans.

## A Time Line of AI

**After a century of ups and downs, artificial intelligence is getting smarter.**

**1914**

In what would come to be described as the world's first computer game, Spanish inventor Leonardo Torres y Quevedo debuts El Ajedrecista, a machine that can automatically play chess thanks to a simple algorithm built into its mechanical design.

**1943**

Neuroscientist Warren McCulloch and logician Walter Pitts present a logical calculus based on neuron-like "logic units" that can be connected together in networks to model the action of a real brain.

**1950**

In a paper that helps establish a practical goal for artificial-intelligence research, Alan Turing proposes a game to answer the question "Can machines think?" He predicts that by 2000 computers will be able to pass as human more than 30 percent of the time.

oped to categorize movies and TV footage when GE owned NBC Universal) with CAD drawings and data from cameras and infrared detectors, GE has improved its detection of cracks and other problems in airplane engine blades.

The system eliminates errors common to traditional human reviews, such as a dip in detections on Fridays and Mondays, but also relies on human experts to confirm its alerts. The program then learns from that feedback, says Colin Parris, GE's vice president of software research.

AI can be a driver of new products and services, too. Through its MyFitnessPal exercise- and calorie-tracking app and other products, sportswear maker Under Armour is connected to 160 million consumers. But rather than merely being limited to logging people's exercise results, the company made a deal with IBM's cognitive computing business, Watson, to combine its data about fitness and nutrition routines with information gleaned from research studies and other third-party data on sleep, activity, fitness, and nutrition. The goal: to tell people with a given goal how they can achieve it, making the company more relevant to those 160 million customers.

To companies like USAA and Under Armour, the future of AI looks less like the anthropomorphic robots in movies and more like tools that get better all the time. And despite fears that AI will lead to the widespread replacement of workers, human judgment and feedback remain integral to improving machine-learning systems. As John Giannandrea, vice president of engineering at Google, told writer Robert D. Hof for his story later in this report: "Even if you have a fancy car, you still have to decide where to go." *—Nanette Byrnes*

ROBERT RISKO

**Expert Q&A**

# Machine Learning for Everyone

Recent advances are making machine learning useful outside the tech industry, says the leader of the Google Brain research group.

● A lot of the computational plumbing that powers Google owes something to Jeff Dean. He built early versions of the company's Web search and ad systems. And he invented MapReduce, a system for working with big data sets that triggered a major shift across the computing industry.

Dean is now laboring to reinvent the inner workings of Google and the wider world all over again. He leads the Google Brain research group, which aims to advance machine learning—the art of making software figure out how to do things for itself instead of being explicitly programmed. Software from Google Brain is now drawn on by more than 600 teams inside Google, often for internal systems invisible to consumers. But in the past year, technology originating in Google Brain has also delivered major upgrades to Google's Web search, spam filtering, and translation services.

Machine learning has a longer history inside Google, where engineers have trained software to show people Web pages relevant to their search queries, select ads related to content they are looking at, show ads people will click on, and pick videos to recommend on YouTube. It is one of many companies that expanded investment in machine-learning research after software that passes data through networks of simulated neurons produced breakthrough results in speech and image recognition.

Now Dean says that before long, the kind of technology his team builds will come to many other industries besides computing. He met with *MIT Technology Review*'s Tom Simonite at Google's headquarters in Mountain View, California.

**How has more powerful, easy-to-use machine learning changed the way teams inside Google work on new problems and products?**

It's been a very big change. In the past five years machine learning has dramatically expanded the scope of what is possible using computers, especially in areas like computer vision and language understanding. This naturally leads to great new products and features—for example, the search facilities of Google Photos [where you can search your photos using terms like "dog" or "beach"], or the Gmail Smart Reply capability. But it also enables Google engineers to think more ambitiously about what sorts of problems they might tackle. By way of analogy, five years ago computers couldn't see very well. Now they can see very well in

**1956**
John McCarthy, Marvin Minsky, and Claude Shannon organize a summertime research meeting at Dartmouth that brings together the leading thinkers on information theory, artificial neural networks, and symbolic logic, christening the field "artificial intelligence."

**1958**
Oliver Selfridge presents a paper in England describing Pandemonium, a new model of a neural network based on lower-level "data demons" working in parallel with higher-level "cognitive demons" in order to perform pattern recognition and other tasks.

**1960**
Frank Rosenblatt demonstrates the Mark I Perceptron, an attempt to create an artificial neural network for image recognition that the *New York Times* calls the first step toward a computer "able to walk, talk, see, write, reproduce ... and be conscious of its existence."

**1961**
Marvin Minsky publishes his foundational paper, "Steps Toward Artificial Intelligence."

some circumstances, and so this naturally expands the sets of things we believe can be accomplished.

**You led development of TensorFlow, software that powers Google's machine-learning research as well as products like a new Gmail feature that composes replies to e-mails. Now the company is giving it away for free. Why?**
Having a common way of expressing machine-learning ideas is really helpful. There's a lot of potential for machine learning all around the world. We're seeing it in academia, at other companies, in government.

**Will every industry end up relying heavily on machine learning?**
I think there are a lot of industries that are collecting a lot of data and have not yet considered the implications of machine learning but will ultimately use it. Transportation, with self-driving vehicles, is going to be a big use of machine learning. Health care has a lot of interesting machine-learning problems—outpatient outcomes, or when you have x-ray images and you want to predict things. I don't think there's one industry that's going to be affected; I think there are going to be lots.

**Machine learning is going to become a fundamental component of applying computing?**
Yeah, absolutely. The enrollment in computer science program machine-learning classes is shooting through the roof.

It's just going to be expected that people have some basic understanding of machine learning and have done a few projects, [and want to] use machine learning.

**Deep Learning**

# How AI Is Feeding China's Internet Dragon

China's biggest Internet company, Baidu, is pushing an ambitious effort to add artificial intelligence to its products.

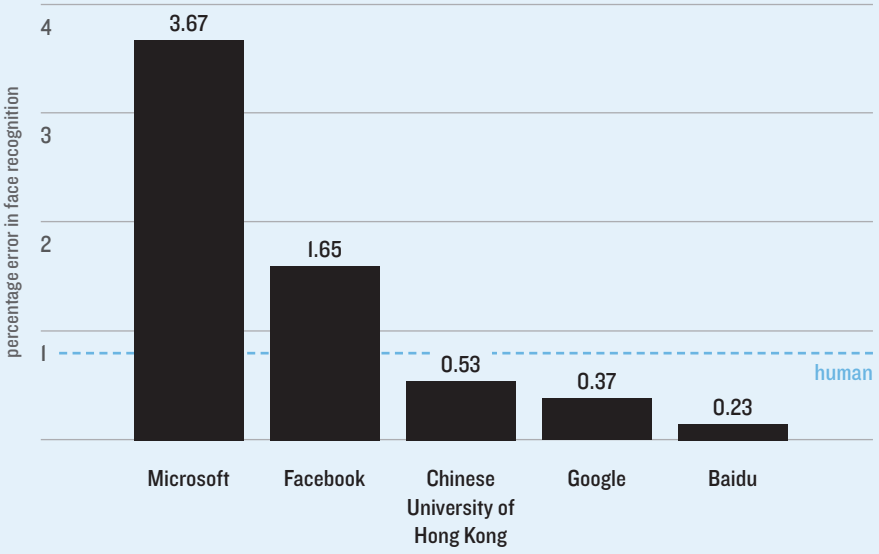
● Shortly after walking through the front doors of Baidu in Beijing last November, I was surprised to notice that my face had transformed into that of a cheerful-looking little dog. As I chatted with one of Baidu's AI researchers, the version of me shown on his smartphone had sprouted a very realistic-looking wet snout, fluffy ears, and a big pink tongue.

The trick was performed on an app called Face You, released by Baidu last Halloween, which lets you add all sorts of spooky effects or animal characteristics to a digital image of your face. Face You makes use of an AI technique called deep learning to automatically identify key points on a person's face, so that software can then position and stretch a virtual mask with amazing accuracy.

Deep learning is driving a lot more than just goofy apps at Baidu, though. It is making existing products smarter and helping the company's engineers dream up many entirely new ideas.

Baidu is one of several companies—Facebook, Google, Microsoft, and IBM among them—that are using deep learning for new applications, such as training computers to hold a conversation, while "migrating older applications from 'conventional' machine learning to deep learning," says Yann LeCun, a professor at New York

**Placing That Face**
As of 2015, groups reported different results using AI techniques like deep learning on large data sets, but computers are sometimes better than humans at recognizing a face.




BAIDU

**1966**
Joseph Weizenbaum demonstrates ELIZA, the world's first chat program, which is able to converse using a series of preprogrammed phrases, sometimes to comic effect.

**1972**
AI takes a hit when philosopher Hubert Dreyfus publishes "What Computers Can't Do," a manifesto challenging the predictions of AI researchers, and scientist James Lighthill pens a pessimistic review of progress in AI research in the U.K., leading to funding cuts.

**1979**
A backgammon program developed by Hans Berliner defeats the reigning world champion in a match, the first time a computer has defeated a champion-level competitor in an intellectual game.

**1984**
Douglas Lenat begins the Cyc project, an ambitious attempt to create a common-sense knowledge base that can eventually become self-educating. Little progress is seen for decades.

University, one of the key figures in the history of deep learning, and the director of AI research at Facebook. This is occurring at an impressive pace because deep learning has proved so effective at recognizing patterns and making predictions from data.

transform its ad system, significantly improving revenue, and powered all-new efforts like the autonomous driving system Baidu demonstrated in December. "The number of deep-learning applications grows each day," he says.

**Deep learning has been used to improve Baidu's antivirus filters and to predict when a hard drive in one of its giant server farms will fail, among other things.**

Deep learning is essentially an especially effective type of machine learning, a way of having computers program themselves after gobbling up vast quantities of data. It involves feeding data to a large network of simulated neurons, which then gradually learn to recognize abstract patterns in that input. A trained network can then, for instance, spot objects in an image, or determine whether a new e-mail message is legitimate or spam.

The technique is certainly helping Baidu maintain its reputation as one of China's most innovative home-grown enterprises. By just about any measure, Baidu is China's most successful Internet business: over 92 percent of the country's more than 536 million Internet search users employ its portal services and mobile apps. And it continues to grow. In the past year it has moved into new areas, including music streaming, insurance, and banking.

Baidu is using AI to move quickly in a dynamic and competitive tech landscape, says Andrew Ng, the company's chief scientist and a prominent machine-learning expert. Two years ago the company created an internal group called the Institute of Deep Learning to explore ways to apply the technology across the company. Since then, Ng says, deep learning has helped

Baidu's Deep Learning Institute often collaborates on AI projects with a Baidu group located in the United States, called the Silicon Valley AI Lab. The U.S. lab was opened in 2013 to attract AI talent already working or studying in the area.

One of the first things Baidu did after setting up the institute, Ng says, was create a deep-learning platform called Paddle that engineers in other departments could use. And researchers from the institute are often embedded within other departments. As a result, deep learning has been used to improve Baidu's antivirus filters and to predict when a hard drive in one of the company's giant server farms will fail, among other things.

As I walked through the institute's offices at Baidu HQ, evidence of frantic activity and experimentation were all around. The lab recently moved to another building on Baidu's campus to accommodate a larger team, and dozens of hastily set-up desks were cluttered with boxes yet to be unpacked. On one bookshelf sat a drone, which researchers were using to build 3-D models of street views.

Jiawei Gu, a youthful researcher, demonstrated the face-morphing app, and he said the techniques used to build it might enable the company to branch out into virtual reality. For instance, they could provide a way to bring real-world objects into virtual environments.

Jiawei then showed me a wearable device Baidu has created to help blind or partially sighted people navigate the world. Called DuLight, the device hooks onto your ear like a Bluetooth headset, captures whatever's directly in front of you, and taps into a deep-learning-based image recognition system to identify it.

Jiawei pointed DuLight at a chair and potted plant, and it said: "Recognizing ... light plastic chair ... recognizing ... lush green potted plant." When he pointed the device at me, it said: "A man smiles, about 37 years old" (a close guess). He said it could be configured to remember someone's name and identify that person later.

AI, in the form of deep learning, has already helped improve key Baidu products, including the core search algorithm, by making image search far more accurate. And it has increased the accuracy of the company's voice recognition engine, which enables voice search as well as a relatively new voice-controlled personal assistant called DuEr. Speech technology

**92%**

Proportion of Chinese search users who use Baidu services

could be especially important to Baidu's future in China, as it offers a more elegant way of using a mobile device than entering Chinese characters on a tiny screen.

"Any company with a lot of data should seriously consider deep learning," Ng says. "It is a superpower that turns huge amounts of data into huge amounts of value." —*Will Knight*

**1987**

Ernst Dickmanns and collaborators equip a Mercedes van with video cameras, microprocessors, and other electronics to demonstrate autonomous driving at almost 60 miles per hour. After much other AI research falls short, DARPA cuts the project's budget.

**1997**

IBM's Deep Blue chess computer avenges its prior defeat to world champion Garry Kasparov in a tense match commemorated in a documentary film, *The Man vs. the Machine*.

**2000**

Cynthia Breazeal designs a sociable humanoid robot named Kismet that is able to express emotion and recognize cues from interaction with humans.

**2004**

DARPA sponsors its first "Grand Challenge," which pits research teams against each other to design driverless vehicles capable of independently traversing the Mojave Desert.

**AI/Human Collaboration**

# Man and Machine

Despite many advances, AI still works best when paired with humans.

● Engineers at Pinterest constantly create new artificial-intelligence algorithms to help its users find what they're looking for among billions of pictures of food, products, houses, and other items. Matching search queries with relevant images is crucial to keep users coming back. But until last year, it could take days to test the effectiveness of each new algorithm.

To fine-tune its machine learning and provide better search results faster, Pinterest turned to an unexpected source: human intelligence. It hired crowdsourcing companies such as CrowdFlower to marshal people to quickly do "microtasks" such as labeling photos and assessing the quality of search results. In an hour, the workers collectively could test hundreds of search terms to see if results matched well enough.

For all the recent advances in AI, human beings remain more adept than machines at distinguishing, say, a tile mosaic from a similar pattern on a blanket. "It will be a long way out before machines will be able to do this," says Pinterest data scientist Mohammad Shahangian.

Pinterest's experience reveals a sometimes forgotten truth: AI and machine learning depend on people as much as on math. Google's search engine and ad system use thousands of human "raters" to assess the quality of its AI-driven search results and help identify scam ads. Facebook's facial recognition software asks people to label their photos to improve accuracy. Deep learning, a branch of AI responsible for recent breakthroughs in speech recognition, language translation, and image analysis, can require extensive human training on hand-picked data sets.

Like Pinterest, many companies hire CrowdFlower, Amazon's Mechanical Turk, or other crowdsourcing services to clean up the data that must be fed into most AI systems in order to teach them the concepts and relationships they need to know for particular tasks. Workers perform such tasks as analyzing linguistic sentiment on Twitter and weeding out offensive user-generated photos or videos.

Sometimes companies set up tasks so people perform them without even realizing it. For example, key in the amount of a check you're depositing that the automated teller machine couldn't read, and you're improving the bank's system.

But even if humans currently can do some of this work more accurately than machines, it seems likely that AI should eventually be smart enough to catch up. "This is a temporary embarrassment," says neuroscience researcher Jeff Hawkins, cofounder of the machine intelligence firm Numenta—though "temporary" could extend to years or even decades, experts say.

Some AI researchers believe the most useful model will be a hybrid system designed at the outset for machines and humans to work together as more equal partners. The nonprofit Intermountain Healthcare in Salt Lake City, for instance, is running a pilot program to support young diabetic patients starting to live on their own, when they tend to suffer gaps in care. A smartphone app provides personalized advice in real time, thanks to a cloud computing system from Austin-based CognitiveScale. Using data on factors such as a patient's behavior and diet, it can determine what is most affecting the patient's blood glucose level at any given moment, suggesting when to eat and even providing reviews of appropriate nearby restaurants.

Others are melding human intelligence and AI in even more intimate ways. Unlike Apple's Siri, Facebook's virtual assistant M uses people to help make decisions. After the AI picks three local restaurants, for example, human "trainers" might jump in to ask whether a person wants a certain kind of food or a window seat, then book the table online. The trainers, whose actions are tracked and fed back into the system, help the AI learn to do more on its own.

**Pinterest's experience reveals a sometimes forgotten truth: AI and machine learning depend on people as much as on math.**

The ultimate dream of many AI researchers is to create machines that can think as well as people. But today human judgment and creativity remain indispensable. "Even if you have a fancy car," notes John Giannandrea, vice president of engineering at Google, "you still have to decide where to go."

*—Robert D. Hof*

**2011**

IBM's Watson defeats *Jeopardy!* champions Ken Jennings and Brad Rutter in a televised two-game, three-night face-off that ends with the computer amassing more than three times the winnings of its human competitors.

**2012**

A team from Geoff Hinton's lab wins the ImageNet Large Scale Visual Recognition Challenge with deep-learning software that could within five guesses identify a thousand types of objects about 85 percent of the time, a huge improvement in accuracy.

**2014**

Google acquires DeepMind Technologies, a small London-based startup focused on deep learning, a relatively new field of artificial intelligence that aims to achieve tasks like recognizing faces in video or words in human speech.

**2016**

Google's AlphaGo decisively beats the world champion of the complex board game Go.

Work Tools

# Siri for Business

While Apple's Siri and Microsoft's Cortana get the attention, AI-powered assistants and software geared toward businesspeople are increasingly popular too. By Elizabeth Woyke

## Clara Labs

**What it makes:** "Virtual employee" that schedules meetings over e-mail. Users copy "Clara" on meeting requests. It e-mails the other party, determines the best meeting times based on users' specified preferences, and sends calendar invites once details are finalized. Cost ranges from $199 to $499 per month per user, with custom pricing available for teams. A more expensive version of Clara can make restaurant reservations for in-person meetings through OpenTable and RSVP to event invites on users' behalf. In use at hundreds of companies, including Stripe, Houzz, and AngelList.

**Target customer:** Professionals who participate in meetings.

**How it works:** Machine learning and natural-language processing. Uses both to understand the intent and context of users' e-mails, automatically answer if straightforward, and "predict" responses if complicated. Messages are the product of algorithms, but human contractors get involved in complex situations.

## DigitalGenius

**What it makes:** Customer-service automation platform. Tool can answer basic questions such as "Does this car come in green?" on its own, in a conversational way, using text messaging, social media, e-mail, or live chat. For more complicated queries such as "Is this car the most eco-friendly vehicle you sell?" it assists human agents with intelligent prompts, such as "Yes, this car is electric and manufactured using renewable raw materials." Corporate customers pay monthly based on degree of automation and usage. Actively deployed with several Fortune 1000 clients, including Unilever.

**Target customer:** Large company call centers in financial services, airlines, or other industries.

**How it works:** Deep learning, machine learning, natural-language processing, and neural networks. Asks corporate customers for customer-service-related chat logs, e-mail transcripts, and Facebook and Twitter messages and feeds them into its algorithm. Process creates customer-service software for clients.

## Howdy

**What it makes:** Conversational software interface, a.k.a. "chatbot," that automates simple, repetitive tasks inside Slack, the popular corporate messaging app. Most commonly used to collect work status updates and lunch order requests from groups. Bot polls team members via text, aggregates their responses, and distributes written reports to each person. Users can also program Howdy to ask anything they want by typing questions into a written script. When activated, the bot runs the script and poses the questions as chat messages. Free while in beta, but will eventually carry monthly fee.

**Target customer:** Teams of up to 20 people that need help automating their day-to-day processes and organizing their information.

**How it works:** Machine learning and natural-language processing. Uses natural-language processing to understand what users are requesting (in their Slack messages) and trigger the correct (prewritten) text. Uses machine learning to train and improve its system.

## Kasisto

**What it makes:** Financial institutions embed this personal assistant in their mobile apps to improve customer experience. Can answer more than 1,000 banking-related questions and understand conversational voice and text commands. Enables consumers to check their account balances, understand spending patterns, search transactions, transfer funds, and locate nearby ATMs. Subscription fee is annual and based on usage. Company is a spinoff of SRI International, the research institute that helped develop the technology behind Apple's Siri, though the two systems are independent.

**Target customer:** Retail and commercial banks, wealth management and credit-card providers.

**How it works:** AI reasoning, machine learning with deep neural networks, natural-language processing, and speech recognition. Uses natural-language processing to rapidly identify users' intentions and AI reasoning to help users achieve their objectives in the most efficient manner.

## Meekan

**What it makes:** Scheduling robot lets teams arrange meetings by typing plain English commands within Slack. Understands phrases such as "We want to have a meeting around noon, before July 4" and analyzes employees' calendars to suggest the most convenient times. Can help book flights through U.K.-based comparison engine Skyscanner. Shows users shortest flight between origin and destination, cheapest flight, cheapest nonstop flight, and earliest arrival. Currently free, but large corporate clients may eventually have to subscribe. Used by 3,100 companies, including AOL and Nike.

**Target customer:** Any company that uses Slack.

**How it works:** Uses natural-language processing to infer users' intentions from their messages and the context and desired format of the meeting in question. Uses machine learning to discern users' preferences. Uses AI reasoning to identify what meeting times would best accommodate attendees given time zones.

## x.ai

**What it makes:** Intelligent agent named Amy (or Andrew, if you prefer) that schedules meetings over e-mail. Similar to Clara (see above) in functionality (but with less human intervention), these assistants currently schedule tens of thousands of meetings each month. Users include employees at LinkedIn, Spotify, and Uber. Service still in closed beta, but planned pricing will be lower than Clara's—around $9 a month for unlimited meeting scheduling and the ability to personalize the assistant's name and e-mail address, with a free option for people who schedule a limited number of meetings.

**Target customer:** Professionals who participate in meetings.

**How it works:** Uses natural-language processing to analyze incoming e-mails for information about people, times, locations, and the sender's intentions, and format the data in a way the intelligent agent can digest. Uses deep learning to interpret the intentions of incoming e-mails and their relevance to a meeting.

JAMES GRAHAM

**Case Study**

# Skype's Gone Multilingual

For decades, machine-learning experts have tried to perfect language translation. Now Microsoft's making strides with Skype.

● Katrina Rippel is a careful speaker who follows all the rules. Hao Chen is a more freewheeling conversationalist. And I'm a nonstop troublemaker, constantly blurting out whatever notions pass through my head. On a recent morning, the three of us met in cyberspace to find out how well (or poorly) we could communicate in a mixture of German, Mandarin, and English. Each of us spoke only our native language.

Donning headphones, we tapped into Skype Translator, a creation of Microsoft's research team. (My chatting partners were part-time consultants to Microsoft, who happened to be thousands of miles away from my West Coast U.S. base.) When I asked Chen where he grew up, it didn't faze me to hear him say: 我在中国的家乡在东北,辽宁省,鞍山市. A few seconds later, a friendly synthetic voice told me: "My hometown is in the northeast in China, Liaoning Province, Anshan."

If only the rest of our exchanges had worked so smoothly. When Chen tried to explain his U.S. travels, Skype mishandled an ambiguous Mandarin noun, telling me he had journeyed to "the cadre of New York." Only when Chen tried different phrasing was Skype willing to make it "the state of New York." When I asked Rippel about her German hometown, Skype's software, expecting me to speak English, not German, heard me say "dressed" instead of "Dresden." So it created a gibberish sentence, in which the German word *bekleidet* appeared instead of her city name.

As such stumbles show, machine-based translation of everyday speech isn't there yet, despite 30 years of trying. It's our own fault, really. If we spoke with the clarity and precision of United Nations diplomats, then artificial-intelligence tools could decode everything according to well-established patterns. The more we rely on uncharted words or syntax to get our thoughts across, the harder it is for translation software to get everything right without extra help.

Even so, Microsoft, Google, Baidu, Facebook, IBM, and many others are vying for supremacy in this difficult field. Offering top-grade voice recognition and translation can become an attractive calling card that helps lock in customers for many other services. These range from Internet search to cloud computing, in which data storage and processing are provided via remote servers and an Internet connection.

Worldwide cloud and infrastructure spending topped $115 billion last year and is growing at a 28 percent annual rate, according to Synergy Research. Real-time translation can help competitors' overall suites of cloud services stand out in what otherwise becomes a price-driven commodity business. For now, most translation services are available free of charge, but paid alternatives may emerge as global enterprises seek customized translation tools that work even better.

Microsoft, in particular, is exploring ways that corporate users can build greater capabilities atop the basic Skype Translator engine that Rippel, Chen, and I tested. One area of interest: helping customers load in thousands of specialized terms, reference documents, sample conversations, and quirky locutions ahead of time. That way, "Dresden"-type problems should be much less likely to occur.

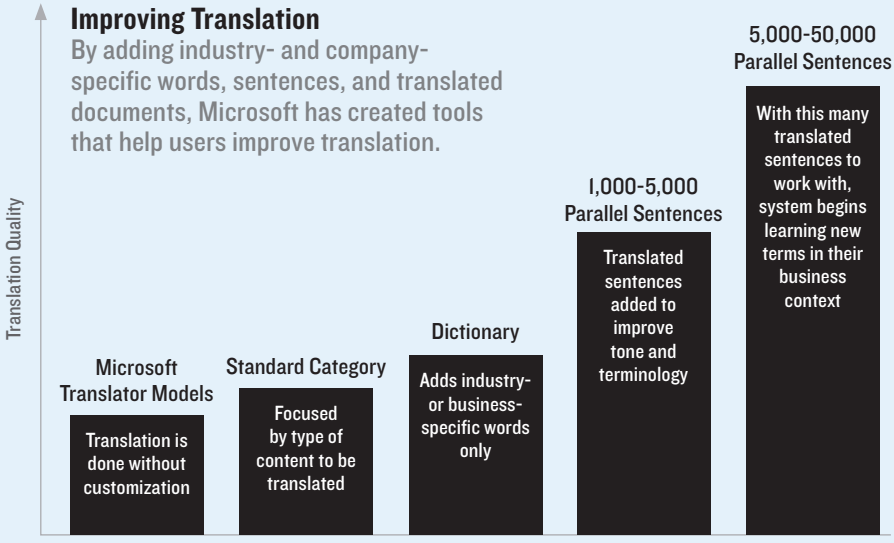
Translation software works much better if it can tap into a hefty database of language patterns that particular speakers are likely to use, explains Microsoft research strategy director Vikram Dendi. Management consultants may use terms like "delta" and "granularity" in contexts that seem unthinkable to the rest of us. Industrial chemists may banter about more than a dozen different kinds of phthalates. And inside any big company, nicknames for projects, processes, and top executives are endless.

Since 2011, Microsoft has allowed big customers to load their own glossaries or written materials into specialized text-translation databases. That's meant to produce more reliable results than Microsoft's basic Bing service provides, especially on dense technical material. More than 100,000 users have opted for customization, Dendi says. Light users may pay as little as $40 a month; heavy users such as Adobe and Twitter may pay far more.

Microsoft has tried a wide range of strategies to crack translation since the mid-1990s, when company founder Bill Gates predicted that speech recognition would be widely available within 10 years. Early approaches relied heavily on attempts to catalogue specific rules of grammar and usage. Starting in 2009, Microsoft broadened its emphasis. Statistical techniques

## Improving Translation

By adding industry- and company-specific words, sentences, and translated documents, Microsoft has created tools that help users improve translation.




DATA SOURCE: MICROSOFT

have been paired with neural networks, a machine-learning system based on the structure and self-teaching nature of the human brain.

Currently, Microsoft uses five layers of neural nets to analyze speech, according to Peter Lee, head of the company's research division. The lowest layers analyze sounds on a level that's as rudimentary as the way image-analyzing software looks for edges and surfaces, without making any attempt to figure out what objects might be. As with many advanced machine-intelligence approaches, there's some mystery to how it works, even to the researchers involved. "It has nothing to do with words or phonemes," Lee says, referring to the sounds that distinguish one word from another. "I don't think any of us understand exactly what the bottom layer is looking at. But it works surprisingly well."

Microsoft's researchers have also been making greater use of what's known as "long short-term memory." When recognizing speech or translating, neural nets make a series of guesses that keep getting revised as new information comes in. Occasionally, an expected pattern suddenly falters. In such cases, neural nets can do a better job of regrouping if they can revisit the assumptions that led to several words' worth of guesses. Keeping a longer trail in the system's short-term memory makes such retracing and subsequent corrections possible.

It takes at least 4,000 hours of spoken samples—and millions of words of text—to train Skype Translator's neural nets in each new language. Arul Menezes, head of Microsoft's machine-translation team, says he had expected difficulties in languages such as Arabic, where speakers' accents can vary widely. But by collecting samples of enough different speakers' voices, Menezes says, it's been possible to develop Skype Translator's "ear" for different intonations to the point that regional accents aren't a problem. The same applies to the differences between male and female voices.

Other variations in everyday speech turn out to be trickier. The neural nets are exquisitely sensitive to differences in microphones. (Humans may be good at detecting the difference between static and speech, but that's much harder for machines to master.) Pauses in speech are problematic, too. As Menezes notes, "People generally don't pause at the end of a sentence. They pause elsewhere. Pauses end up being useless in detecting when a sentence begins or ends. You have to go by the words themselves."

Sorting out the right translations for ambiguous words is a never-ending challenge, too, Menezes acknowledges. While speaking German, Rippel frequently uses the word *Sie*, which can mean she, you, or they, depending on the situation. Skype Translator gets it right about 80 percent of the time.

Similarly, Skype Translator stumbles slightly when Chen discusses family sizes in China. Regardless of government policies, Chen tells me, the sheer cost of parenting in China means that "a lot of people only want to give birth to a child."

A few minutes later, sitting in Building 99 of Microsoft's headquarters, Menezes and I review a transcript of the conversation. Menezes ruefully points to the child-raising exchange. "That should be 'one child,'" he says. "But in Chinese, there's no distinction between 'one' and 'a.' There's a difference in English, but it has to be picked up entirely in context."

"I don't think professional translators are quaking in their boots yet at what we're doing," he adds, with a thin smile. "Their jobs are safe for quite a while."

Rippel, a professional translator, isn't nearly so critical. As long as users speak slowly and keep sentences short, she says, automated services such as Skype Translator can do a useful job of overcoming language barriers.

"It's very important that this tool exists," she says. "In current times, it's more important than ever for people in all communities to be able to talk to one another."

*—George Anders*

JAMES GRAHAM

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# Once More Unto the Breach: What It Takes to Defeat Cyberattackers

Cyberattacks are a fact of life worldwide, with intruders breaching more and more organizations each day. Why are we so vulnerable? And what can we do to make our systems more secure?

Picture this: It's the middle of the night, and the phone rings. There's an emergency at work—a network breach.

"I've received calls at the most inopportune times," says Marshall Heilman, vice president and executive director, incident response and red-team operations at the cybersecurity firm Mandiant, a FireEye company. "In 2014, I got a call just before Thanksgiving. I had to go in to help a company that had been hit by an advanced attacker, and it was serious," Heilman recalls, adding that his team battled another breach on Christmas Eve in 2015. "Hackers are strategic about the holidays," he says. "They compromise organizations at those times because that's when they expect the defenses to be down."

Year-round, attackers also capitalize on an asymmetry between them and their targets, says Andrzej Kawalec, chief technology officer for Hewlett Packard Enterprise (HPE) Security Services. "Most organizations today rely on the walls and moats of yesteryear, thinking they're defending against catapults and cannons, while attackers instead use drones and highly targeted stealth technology." Meanwhile, as HPE's *Cyber Risk Report 2016* finds, 86 percent of organizations currently lack adequate cybersecurity capabilities.

How long do adversaries spend beyond the perimeter before being detected? In 2015, the median time from compromise to discovery was 146 days, according to the *M-Trends 2016* Report

146
days

Median amount of time attackers spent inside networks before being detected

Source: *M-Trends 2016 Report*, Mandiant

**Marshall Heilman, Vice President and Executive Director, Incident Response and Red-Team Operations, Mandiant (a FireEye company)**

**Andrzej Kawalec, Chief Technology Officer, Hewlett Packard Enterprise Security Services**

**Chris Leach, Chief Technologist, Hewlett Packard Enterprise Security Services**

by Mandiant. While most attacks don't turn into major breaches, constant cybersecurity threats are a fact of life, Heilman says. "A successful attacker can gain network access over the course of a week, or even in just a couple of days. So if you can't prevent an attack—if you know the attacker is going to get in no matter what—then you want to detect it as fast as possible, and then respond to it."

HPE and FireEye respond to thousands of such breaches annually, providing incident response, compromise assessment, and threat detection services to enterprises worldwide.

## The Attack Lifecycle

Regardless of whether the perpetrator is a "hacktivist," a cybercriminal, or a state-sponsored threat actor, the cadence (or attack lifecycle) remains essentially the same, Heilman says. His team's work skews toward advanced persistent threats (APTs), which are situations where perpetrators gain access to a network and stay there for a long time.

After they have researched a target company's systems and people, such attackers take the next step: infiltrating a network by tapping into a weakness—in 80 percent of cases, by sending a "spear-phishing" email, Heilman says. "By making a human click on a link or open up a file, the attackers can run their own malicious code, which often creates a back door into the network." That establishes a foothold from which attackers can control their activities in that environment.

Next comes "privilege escalation," Heilman explains: "They take the rights they've gained from the systems that they've compromised and escalate them to a local administrator or a main administrator, to root access, or to whatever they may need for greater access to systems and data." That's often accomplished by stealing credentials, cracking passwords, or exploiting vulnerable software.

Once the attackers have obtained administrative rights, they've reached APT status. They undertake reconnaissance, moving laterally throughout the company's computer systems, taking stock of what they're seeing, noting the roles and responsibilities of key individuals and the location of information they want. Perpetrators often maintain presence, or "persistence," by installing multiple back doors throughout the environment. "Then they're going to try to accomplish whatever they came to do, which is often stealing information—intellectual property, financial data, merger and acquisition details or personally identifiable information, for example," Heilman says. When they've completed their mission, attackers retain access where possible in case they want to return.

## Tips for Targets: Think Like the Bad Guys

In Heilman's view, your best approach to defeating attackers is adopting their mindsets—not responding to their next moves, but anticipating them. You must also recognize and detect anomalous behavior in your organization.

Kawalec encourages enterprise executives to become acquainted with their company's threat landscapes. Knowing which assets are most critical, and thus must be vigilantly protected, is a significant offensive advantage against cyberthreats. "Understand what is valuable in your organization. Who is going to try and get those major assets? That gives you a view of risk," he says. "Then understand whether you've been compromised and where you're vulnerable." Finally, the biggest issue: "Do you know exactly what you're going to do when the phone rings in the event of a breach?" Kawalec asks. "Those are the big questions that any cybersecurity leader or chief information security officer should be able to answer on behalf of their organization—because if they can't, they're in trouble."

> "Do you know exactly what you're going to do when the phone rings in the event of a breach?" — Andrzej Kawalec, Chief Technology Officer, Hewlett Packard Enterprise Security Services

As with many other crimes, the initial 48 hours following a breach are the most critical. But how quickly and how well an organization responds and recovers is determined by what has been done *before* the incident. "Your initial emergency response is dependent entirely and fundamentally upon the work you did months earlier: Write and understand a breach-response plan, identify the roles and responsibilities of the people involved, especially the first responders, and then train people," Kawalec explains. Drills are crucial as well: "Run scenarios and red-team reviews—or realistic simulations—and take the company board through a real-life experience of a cyberattack," he says. "That way, when they do experience it for real, it's not for the first time."

And it won't be the last time. As HPE's latest Cyber Risk Report documents, the volume of breaches has increased, and although attackers are still using relatively old methods to scale firewalls and bypass antivirus software and other traditional defenses, they're also becoming more sophisticated. They're adjusting their techniques to circumvent newer cybersecurity technologies. In addition, they're developing intricate business models in which they collaborate on attacks, and they're expanding their reach into the Internet of Things (IoT), including cell phones, tablet computers, and cloud services. It all adds up to massive expenses for organizations: The *2015 Cost of Cyber Crime Study: Global*, conducted by The Ponemon Institute and sponsored by HPE, estimates the mean annualized cost of cybercrime for 252 benchmarked companies at $7.7 million in just one year, with the security-research firm reporting that some lost as much as $65 million.

Dealing with increasingly sophisticated adversaries requires correspondingly sophisticated lines of defense. With that in mind, HPE has developed an industry-standard Cyber Reference Architecture (CRA) that provides customers with a blueprint for advanced threat protection services and incident response capabilities. Among its other functionalities, the CRA incorporates FireEye's most current insights regarding APTs, those situations in which attackers establish strong footholds and wreak havoc over longer periods of time.

Essentially, the CRA is a "cybersecurity cookbook," says Chris Leach, chief technologist for HPE Security Services. "The reference architecture articulates what your organization should look like: the key areas, the span of responsibilities, and the metrics. It ranges from the strategic part—including running response drills inside a company—to the people, to the ops, to what you should do in an actual breach," he explains. The architecture also includes specific use blueprints, synthesizing the common events and mapping them back to the CRA to see whether it addresses risk and operational risk, Leach adds.

## Partner With the Cybersecurity Experts

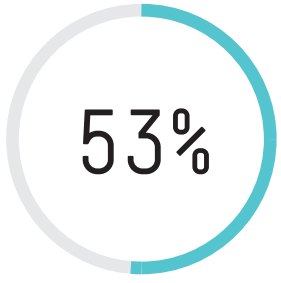
Statistics indicate that companies need outside help. Only 47 percent of the 2015 breaches Mandiant addressed were discovered internally; in 53 percent of cases, companies learned about breaches from external sources, such as law enforcement, the media, customers or suppliers—or even the attackers themselves. Kawalec says such outside notification puts company leaders in a difficult, reactive position. "It means that they find it very hard to control the situation, to command and direct the appropriate response, and also to communicate from a position of strength," he says. "They have to focus on understanding and tracking the behaviors of users and systems, and then match a pattern against something they know is not right."

More and more global companies are turning to HPE for cybersecurity remediation services underpinned by FireEye's advanced threat detection, intelligence, methodologies, and incident-response expertise. Together, the two companies form a powerful partnership in cybersecurity, Kawalec says. "When you consider the resources of a typical security team in a pretty big organization, even large security teams would only be 15 to 100 people. HPE and FireEye are able to project cybersecurity capability for a broad range of companies. That's why people turn to us for that help."

$7.7 million

Mean annualized cost of cybercrime at 252 organizations worldwide

Source: *2015 Cost of Cyber Crime Study: Global*, The Ponemon Institute, sponsored by HPE.




Percentage of breaches discovered from external sources such as law enforcement, media, customers, suppliers, or even attackers themselves

Source: *M-Trends 2016 Report*, Mandiant

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# Reviews

## What If Apple Is Wrong?

New layers of secrecy on smartphones might damage the criminal justice system in return for only marginal gains in our personal privacy.

By Brian Bergstein
Photographs by Jonno Rattman

**Soon after Devon Godfrey was shot to** death in his apartment in Harlem on the evening of April 12, 2010, officers with the New York Police Department thought they knew who did it. Security cameras had captured a man entering and exiting the apartment around the time that they thought Godfrey was killed. They arrested the suspect on a charge of murder.

At that point in a case, prosecutors in New York have less than a week to gather the facts needed to persuade a grand jury to indict the suspect. So the prosecutor on this case, Jordan Arnold of the Manhattan District Attorney's Office, worked through a weekend to dig deeper into the evidence.

Cell phones had been found in Godfrey's apartment, including an iPhone that was locked by its passcode. Arnold recalls doing what he always did in homicides back then: he obtained a search warrant for the phone and put a detective on a plane to Cupertino, California. The detective would wait in Apple's headquarters and return with the data Arnold needed. Meanwhile, investigators looked more closely at the apartment building's surveillance video, and Arnold examined records sent by Godfrey's wireless carrier of when calls and texts were last made on the phones.

*The contact list and text messages on an iPhone found in this New York City apartment in 2010 offered crucial evidence of who had killed the owner of the device.*

With this new evidence in hand, the case suddenly looked quite different. From the wireless carrier, Arnold saw that someone—presumably Godfrey—had sent a text from the iPhone at a certain time. But the recipient of that text had used a disposable "burner" phone not registered under a true name. So who was it? The iPhone itself had the crucial clue. Arnold could see that Godfrey referred to the person by a nickname. People who knew Godfrey helped police identify the man who went by that nickname. It was not the man who was originally arrested. It was Rafael Rosario—who also appeared in the apartment surveillance footage. Rosario confessed and later pleaded guilty.

What would the outcome have been if Godfrey had been killed today, now that Apple has tightened the security on iPhones so that it can no longer get data from them when police come calling? Digital evidence that remains in abundance—revealing, for example, when and where devices were used—probably would have been enough to show that the original suspect did not kill Godfrey. But he

**Don't Panic: Making Progress on the "Going Dark" Debate**
The Berkman Center for Internet & Society
February 2016

**The Ground Truth About Encryption and the Consequences of Extraordinary Access**
The Chertoff Group
March 2016

**Report of the Manhattan District Attorney's Office on Smartphone Encryption and Public Safety**
November 2015

**Keys Under Doormats: Mandating Insecurity by Requiring Government Access to All Data and Communications**
Computer Science and Artificial Intelligence Laboratory, MIT
July 2015

might have sat in jail longer before being cleared, and the actual killer might never have been found.

"Without having had access to the contact list in the devices and the content of text messages, we would have been left, I think, with just surveillance footage," Arnold says. "We may have had to hang our hopes on the ability of someone to come forward and say 'I know who that is.'"

Are we certain we want to eliminate an important source of evidence that helps not only cops and prosecutors but also judges, juries, and defense attorneys arrive at the truth? That essential question got lost in this winter's remarkable confrontation between the FBI and Apple, when the company refused to help the agency pierce an iPhone that Syed Rizwan Farook had used before he and his wife shot 14 people to death and wounded 22 others in San Bernardino, California. In that case, the perpetrators wouldn't be standing trial—they were dead. Investigators already had reams of information on them, including files that Farook's phone had backed up to Apple's iCloud service. A friend accused of buying guns for them had been arrested. And then the FBI found a way into the device after all.

The issue looks much different in crimes like Godfrey's murder. In cases like that, local cops who have much scarcer resources than the FBI can find themselves with little to go on. Evidence that once could be found inside cameras, notepads, address books, calendars, and ledgers often now exists only on phones. And on the phones discovered in Godfrey's apartment in 2010, there was enough evidence to help clarify that one man did not commit murder and another man did.

The argument for opening smartphones to law enforcement is not that we should make police work as easy as possible. In a free society, some criminals will always slip away because of restraints on investigation that are necessary for balancing liberty and security. Evidence is always lost to time, to decay, to confusion, to incompetence, and to murky memories. We will always keep secrets in safes, in encrypted files, and in our minds.

But we need to ask whether too much evidence will be lost in smartphones that now lock away all that they hold—not just message traffic but also calendar entries, pictures, and videos—even when police have a legal right to view those contents. Apple will eventually close the hole that the FBI found into the San Bernardino phone, and now it is exploring ways of cutting off its avenue for giving police data backed up in the cloud, too. What if these new layers of secrecy undermine the justice system without even increasing your privacy very much?

**We're about to find out whether this is still the "golden age of surveillance," now that more and more people carry around a device that is inaccessible by default.**

**Sea change**

When FBI director James Comey and other law enforcement leaders warned in public forums in 2014 that new layers of encryption on smartphones were causing criminals to "go dark," it had a familiar ring of hyperbole. Twenty years earlier, American officials were so worried about criminals cloaking their misdeeds that they sought to force companies wanting to encrypt data to use a Clipper Chip, a piece of hardware designed by the National Security Agency to let the authorities unlock data with a digital skeleton key. The Clipper Chip deservedly died after it became clear that the requirement was unworkable and the chip was hackable. And even without it, investigators still managed to prosecute plenty of criminals, thanks in no small part to technologies such as security cameras, location tracking through cell-phone towers, wiretaps on phone calls, and e-mail and text messages that most people did not bother to encrypt and thus could be gathered under a court order.

Digital evidence was in fact so plentiful that by 2011, privacy scholars Peter Swire and Kenesa Ahmad declared our times "the golden age of surveillance." They and other privacy advocates didn't dispute law enforcement officials' contention that terrorists, cartel bosses, and pedophiles were covering their tracks with encrypted messaging services. But such losses to law enforcement, Swire and Ahmad wrote, were "more than offset by surveillance gains from computing and communications technology."

We're about to find out whether that will remain true as more and more people do their computing and communicating on a device that is entirely inaccessible to police by default and is wiped clean if anyone makes too many attempts to guess the passcode, which is now the only way to unlock the phone. Since Apple redesigned its iOS operating system in 2014 so that it could no longer open iPhones and iPads—and Google followed suit on some Android devices—phones have started to pile up uselessly in evidence rooms. They are not just hindering investigations of certain clever criminals; they're inhibiting every kind of case.

In Baton Rouge, Louisiana, investigators are stuck with about 60 locked devices, including an iPhone belonging to Brittney Mills, a 29-year-old woman who was shot to death at her doorstep one night in 2015, when she was eight months pregnant. The baby was delivered but died

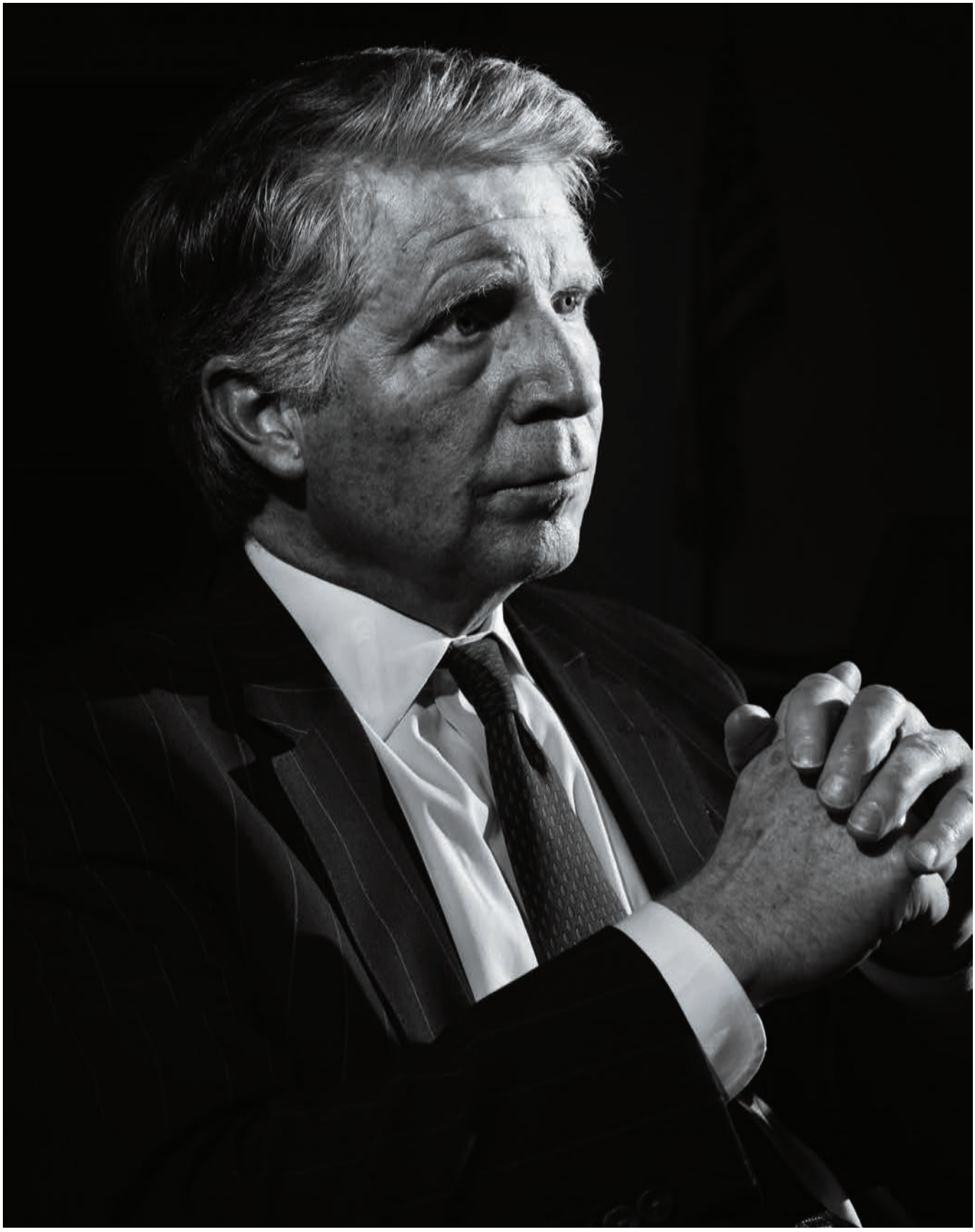

*On early iPhones, forensic tools could try all passcodes until they hit the right one. With later versions, police needed Apple to extract data. Now Apple says it can't do that anymore.*

soon after. Mills had opened the door for the killer, so she probably knew the person. But police could find little physical evidence, and no eyewitnesses have come forward, according to Hillar Moore III, the East Baton Rouge Parish district attorney. Mills's nine-year-old daughter was home at the time, but she only heard the shooting and then hid in the bathroom. Police know which people Mills texted and called the day of her death, but they don't know what was said, and Moore says no suspects stand out in that group.

Mills's iPhone could offer vital evidence. Her relatives have told investigators that she kept a diary on the device. But she hadn't backed her phone up to Apple's iCloud service for three months. No one knows her passcode, and Apple says it can't open the phone. Whether it holds the kinds of clues that cracked Devon Godfrey's murder in 2010 might never be known.

At least for now, however, there have not been enough such cases to convincingly show that the "golden age of surveillance" is ending. "We don't see a groundswell of disruption in law enforcement," says Paul Rosenzweig, a security consultant who helped lead a report on the effects of encryption that was published in March by the Chertoff Group, which advises businesses and governments. He argues that the vast majority of cases that local cops handle do not hinge on evidence on cell phones. "It may well be that three years from now, we'll all look up and say that there's been a sea change," he says. "I suspect not, honestly."

Rosenzweig echoes many computer scientists who say that if the data on phones is encrypted in such a way that the passcode is the only decryption key, identity thieves and other criminals who might get access to your phone will be foiled, a benefit that outweighs the negative consequences. As phones gain functions well beyond communications and



are used for storing medical information or making payments, removing layers of security (or declining to add more) would be a disaster, says Hal Abelson, a computer scientist at MIT.

These protections are in fact so necessary, Abelson says, that it's just too bad if they cause problems for the police—they will have to adapt. He brings up a report published last fall by Cyrus Vance Jr., the district attorney of Manhattan. Vance says that since Apple stopped being able to get into its devices, his office has been unable to carry out more than 215 search warrants for iPhones and iPads, in cases that include homicide and sexual abuse of children. Abelson argues that Vance's office should try to break into the phones, as the FBI ended up doing in San Bernardino. But he does not think Apple should redesign its devices so it can go back to getting data off them for cops. I asked Abelson to consider the most extreme scenario: what if Vance could show that extracting information from those phones was the only way to solve the cases? Abelson was unmoved. "Tough," he said.

**"Are you crazy?"**

In his huge office on the eighth floor of a criminal justice building in lower Manhattan, Cyrus Vance can hear car horns honking even when the windows are closed. One wall has a Richard Avedon portrait of his father, who was Jimmy Carter's secretary of state, alongside mementos from Seattle, where Vance Jr. and his wife raised their two children while he was in white-collar law practice. The other side of the office speaks to the six years he has been the top prosecutor in the nation's financial capital, where he has become known for his data-driven approach to law enforcement. There is a Scotland Yard drink coaster on a conference table, near an easel that has been moved out of my sight because, I'm told, it holds notes on iPhone-related cases.

*Cyrus Vance Jr., the district attorney in Manhattan, says smartphone makers have not shown that older devices that allowed search warrants to be carried out were significantly less secure.*

Vance makes no dramatic claims about "going dark," preferring a measured, lawyerly form of argument. When I tell him that his statistics on inaccessible iPhones don't yet impress many computer scientists, he makes a facial expression equivalent to a shrug. "Some people have made the determination that not being able to do the kinds of work we do is an acceptable collateral damage," he says.

**"It's one thing for the FBI to be in an arms race with the cell-phone companies. It's another thing for Onondaga County, New York ... What are they going to do?"**

"I'm not sure how the individual would respond if someone close to him or her were the victim of a crime and the case might depend on the ability to access a phone. Easy to say, unless it's you. We deal with a lot of victims. We talk to the people it's actually happened to."

To Vance, the right course of action is obvious. He thinks the federal government should pass a law that would require the makers of smartphone operating systems to be able to give data to investigators who come to them with search warrants and devices in hand, as they did before 2014. Vance's proposal would not restrict you from installing apps that encrypt messages, but at least you could no longer pick a phone off the shelf that makes everything on it invisible to police.

Although locked smartphones have held up a small percentage of cases, Vance is convinced a law is needed before the number climbs much higher. To illustrate his point, he describes a case from 2012. A man in Manhattan was taking a video on his iPhone when he was shot and killed by someone who threatened to go after the eyewitnesses if they talked. Investigators got that video and convicted the killer. Now imagine that shooting happening today. If the victim made the video on a stand-alone digital camera, it would be fair game for cops with a warrant. Why should they be unable to see it just because he used an iPhone?

"It's too facile to say 'It's the golden age of surveillance, and you shouldn't be able to get into the phone,'" Vance says. "If your view is that it's [law enforcement's] job to investigate fully, to get at the truth so that justice can be determined by the true facts, then you would take my position, which is: 'Are you crazy? You wouldn't want law enforcement to have access to what may be the most critical evidence?'"

Why can't investigators often do what the FBI finally did in San Bernardino, and figure out a way into phones themselves? Vance says it doesn't serve justice very well to make law enforcement continually scramble to find arcane and expensive ways of catching up with Silicon Valley. He also finds it unrealistic. "It's one thing for the FBI to be in an arms race with the cell-phone companies. It's another thing for Onondaga County, New York, where there's digital evidence on phones of child abuse, senior abuse, fraud. The DA and the sheriff in that county—what are they going to do?"

Can't you ask the National Security Agency to get into phones, much as Edward Snowden revealed that the NSA cracked services run by Silicon Valley? "I cannot," Vance says. (He does not elaborate—but if the spy agency were allowed to help local law enforcement, it would be forced to reveal its methods in court.)

Instead, he says, Apple and Google should stop expecting special treatment not accorded to other corporations. For example, financial institutions had to build complex systems for catching money laundering and other crimes. "Two companies that own 96 percent of the world's smartphone operating systems have independently decided they're going to choose where the line between privacy and public safety is to be drawn," Vance says. "We should ask them to make the same kind of adaptations that we require banks to do."

Most provocatively, Vance contends that today's smartphones might not be meaningfully more resistant to hacking than earlier versions. Even before 2014, you were not exactly a sitting duck; you could erase lost or stolen devices from afar. Computer security experts insist that any system in which your passcode is the only key is safer than a system that Apple or Google can also open. But in an attempt to understand the trade-offs involved, Vance has written to the top lawyers at those companies, asking them to quantify the improvement. How much safer are phones now? Had any outsider ever managed to hack the companies' tools for getting data out of devices that police brought to them? Neither company has responded.

**Is Apple ultimately fighting to uphold personal privacy? Or is it fighting for the right to sell any kind of phone it thinks its customers want?**

### Civil liberties

Apple's legal argument against the FBI boiled down to this: it could not be forced to undo the protections it built into the San Bernardino phone because no law explicitly said it must. The FBI sought to make the company do it under a 1789 law called the All Writs Act, which lets federal courts issue orders to enable the execution of existing laws. Apple counters that this is a path to extreme government overreach, and that it is for Congress, not individual judges, to decide what to require of smartphone makers. Indeed, in February, a judge in a different case found Apple's argument persuasive and denied federal investigators access to a locked iPhone used by a man who has pleaded guilty to dealing methamphetamine.

So on one thing, at least, Apple agrees with Vance: Congress should act.

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## From the archives


**Sun+Water=Fuel**
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**Battling Bacterial Resistance**
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**MIT Technology Review**

The question is how. Apple has carefully avoided suggesting what a new law should say, proposing that a "commission or other panel of experts on intelligence, technology, and civil liberties" explore the subject. But Apple CEO Tim Cook seems confident that such a panel would not advocate limits on the implementation of encryption. "There's too much evidence to suggest that [would be] bad for national security," Cook told *Time* magazine in March.

Yet in that same interview, Cook also appeared to concede that the latest smartphones might indeed get in the way of justice. Asked whether he could accept shutting investigators out of phones in the interest of keeping hackers out too, Cook said he could see a way to let the cops in. If investigators "have a problem with you," he said, perhaps they "can come to you and say, 'Open your phone.' … They could pass a law that says you have to do it, or you have to do it or there's some penalty."

This kind of "key disclosure" law already exists in several countries, including the United Kingdom. But if Cook is serious when he claims that Apple is "defending the civil liberties of the country" against the U.S. government, his suggestion is about as shortsighted as the Clipper Chip.

For one thing, a law requiring suspects to give up their passcodes would be useless with a locked phone belonging to a murder victim like Devon Godfrey or Brittney Mills. Second, a criminal potentially facing decades in prison would be happy to take a shorter term for contempt of court instead. That probably explains why the U.K. and other countries with key disclosure laws are nonetheless considering laws that would put even more restrictions on encryption than what Vance proposes.

But the most jarring aspect of Cook's suggestion is that compelling suspects or defendants to reveal their passwords could weaken the protection against self-incrimination embodied in the Fifth Amendment to the U.S. Constitution, written by people who were obsessed with freedom and privacy. It's not certain that a key disclosure law would be unconstitutional, but multiple U.S. courts have ruled that suspects do not have to reveal passwords because they are "contents of the mind."

So is Apple ultimately fighting to uphold personal privacy and civil liberties? Or is it fighting for the right to sell any kind of phone it thinks its customers want while other people deal with the negative consequences? If it's the latter, that's understandable; like any public company, Apple is obligated to maximize its value to its shareholders. But society is not necessarily best served by letting Apple make whatever phones are optimal for its chosen business strategy, which is to create a shiny mobile vault that people will trust with every aspect of their lives.

"Letting a company lead the debate is a really bad idea," says Susan Hennessey, who studies national security and governance issues at the Brookings Institution and who has criticized Apple for taking an "anti-communitarian" stance. "A company is not able to take into account the full scope of what our values are."

It's very possible that locking cops and prosecutors out of smartphones won't interfere with justice as much as they fear. They might find ample methods of adapting, especially as new technologies arise. But just because some officials have overreacted to encryption in the past doesn't mean we should brush off warnings coming now. The justice system is far from infallible, but it is run by people whose duty is to something more than a set of shareholders.

*Brian Bergstein is executive editor of* MIT Technology Review.

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# Tech Slowdown Threatens the American Dream

Despite the allure of apps and social media, today's digital technologies are doing little to generate the kind of prosperity that previous generations enjoyed, a prominent economist argues. But that doesn't mean we should give up on innovation.

By David Rotman

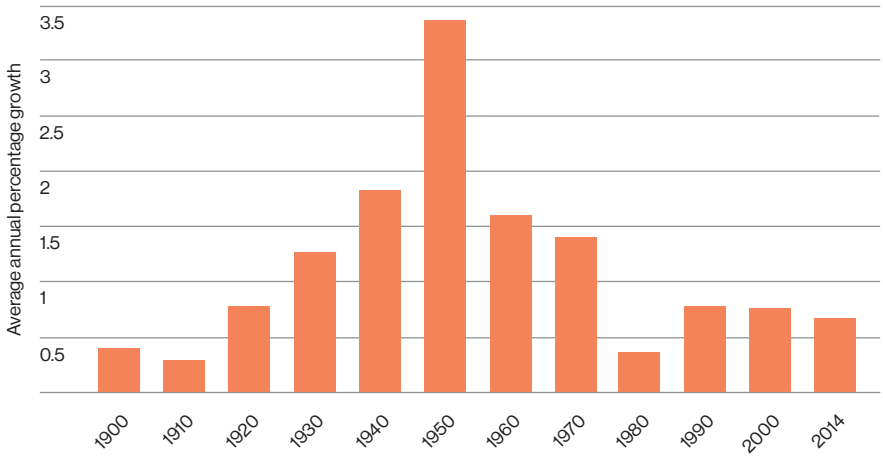
PAUL ROGERS


**In a three-month period at the end of 1879,** Thomas Edison tested the first practical electric lightbulb, Karl Benz invented a workable internal-combustion engine, and a British-American inventor named David Edward Hughes transmitted a wireless signal over a few hundred meters. These were just a few of the remarkable breakthroughs that Northwestern University economist Robert J. Gordon tells us led to a "special century" between 1870 and 1970, a period of unprecedented economic growth and improvements in health and standard of living for many Americans.

Growth since 1970? "Simultaneously dazzling and disappointing." Think the PC and the Internet are important? Compare them with the dramatic decline in infant mortality, or the effect that indoor plumbing had on living conditions. And the explosion of inventions and resulting economic progress that happened during the special century are unlikely to be seen again, Gordon argues in a new book, *The Rise and Fall of American Growth*. Life at the beginning of the 100-year period

**Peak Innovation**

Total factor productivity measures innovation. It peaked in the 1940s and was strong through 1970. Each bar shows a 10-year average prior to the year shown (2014 bar is for 2001–2014).




SOURCE: ROBERT J. GORDON, *THE RISE AND FALL OF AMERICAN GROWTH*

was characterized by "household drudgery, darkness, isolation, and early death," he writes. By 1970, American lives had totally changed. "The economic revolution of 1870 to 1970 was unique in human history, unrepeatable because so many of its achievements could happen only once," he writes.

The book attempts to directly refute the views of those Gordon calls "techno optimists," who think we're in the midst of great digital innovations that will redefine our economy and sharply improve the way we live. Nonsense, he says. Just look at the economic data; there is no evidence that such a transformation is occurring.

Indeed, productivity growth, which allows companies and nations to expand and prosper—and, at least potentially, allows workers to earn more money—has been dismal for more than a decade. Although it might seem as though a lot of innovation is going on, "the [productivity] slowdown is real," John Fernald, an economist at the Federal Reserve Bank of San Francisco, told me. In a recent paper, Fernald and his colleagues traced the sluggishness back to around 2004 and found that the last five years saw close to the slowest productivity growth ever measured in the United States (the data go back to the late 1800s). And Fernald says technology and innovation are "a big part of the story." Some techno optimists have argued that the full benefits of apps, cloud computing, and social media are not showing up in the economic measurements. But even if that's true, their overall effect is not all that significant. Fernald found that any growth spurred by such digital advances has been inadequate to overcome the lack of broader technological progress.

**For most Americans, wages are just not keeping up. Incomes actually shrank between 1972 and 2013. And it's not going to get any better, predicts Robert Gordon.**

Gordon is not the first economist to be unimpressed by today's digital technologies. George Mason University's Tyler Cowen, for one, published *The Great Stagnation* in 2011, warning that apps and social media were having limited economic impact. But Gordon's book is notable for contrasting today's slowdown with the radical and impressive gains of the first three-quarters of the century. Over the course of more than 750 pages, he describes how American lives were changed by everything from the electrification of homes to the ubiquity of household appliances to the construction of extensive subway systems in New York and other cities to medical breakthroughs such as the discovery of antibiotics.

In some ways, though, the most compelling and ominous story is the one that Gordon tells through the numbers. Economists typically define productivity as how much workers produce in an hour. It depends on the contributions of capital (such as equipment and software) and labor; people can produce more if they have more tools and more skills. But improvements in those areas don't account for all productivity increases over time. Economists chalk up the rest to what they call "total factor productivity." It's a bit of a catchall for everything from new types of machines to more efficient business practices; but, as Gordon writes, it is "our best measure of the pace of innovation and technical progress."

Between 1920 and 1970, American total factor productivity grew by 1.89 percent a year, according to Gordon. From 1970 to 1994 it crept along at 0.57 percent. Then things get really interesting. From 1994 to 2004 it jumped back to 1.03 percent. This was the great boost from information technology—specifically, computers combined with the Internet—and the ensuing improvements in how we work. But the IT revolution was short-lived, argues Gordon. Today's smartphones and social media? He is not overly impressed. Indeed, from 2004 to 2014, total factor productivity fell back

to 0.4 percent. And there, he concludes, we are likely to remain, with technology progressing at a rather sluggish pace and confining us to disappointing long-term economic growth.

These numbers matter. Such lackluster productivity growth precludes the kind of rapid economic expansion and improvements in the standard of living that Gordon describes happening in the mid-20th century. The lack of strong productivity to fuel economic growth—combined with what Gordon calls the "headwinds" facing the country, such as rising inequality and sagging levels of education—helps explain the financial pain felt by many. For most Americans, wages are just not keeping up. Except for the very top earners, real incomes actually shrank between 1972 and 2013. And it's not going to get any better, says Gordon. He predicts that median disposable income will grow at a bleak 0.3 percent per year through 2040.

***The Rise and Fall of American Growth***
By Robert J. Gordon
Princeton University Press, 2016

**"Is Innovation Over? The Case Against Pessimism"**
By Tyler Cowen
*Foreign Affairs*, March/April 2016

**Make America great again**

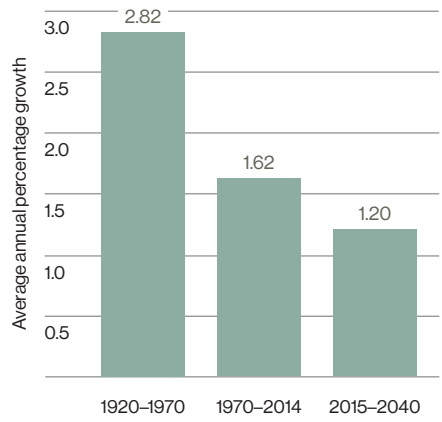
No wonder so many Americans are upset. They sense they will never be as financially secure as their parents or grandparents—and, even more troubling to some, that their children will also struggle to get ahead. Gordon is telling them they are probably right.

If robust economic progress in the first half of the 20th century helped create a national mood of optimism and faith in progress, have decades of much slower productivity growth helped create an era of malaise and frustration? Gordon provides little insight into that question, but there are clues all around us.

Anger over the economy is certainly manifesting itself in the current presidential election. The leading Republican candidate is pledging, somewhat abstractly, to "make America great again," and vaguely similar sentiments reflecting nostalgia for past prosperity are being echoed in the Democratic campaigns—particularly in Bernie Sanders's economic plan that purports to achieve productivity growth of 3.1 percent, a level not seen in decades.

There are also hints that the long-term lack of economic growth is affecting some Americans in insidious ways. Late last year, economists Anne Case and Angus Deaton, both at Princeton, described a disturbing trend between 1999 and 2013 among white men aged 45 to 54: an unprecedented rise in morbidity and mortality that reversed years of progress. This group of Americans was experiencing more suicides, drug poisonings, and alcoholism. The reasons are uncertain. But the authors did cautiously offer one possibility: "After the productivity slowdown in the early 1970s, and with widening income inequality, many of the baby-boom generation are the first to find, in midlife, that they will not be better off than were their parents."

**Call This Progress?**
Productivity growth is lackluster




SOURCE: ROBERT J. GORDON

Speculating on how the lack of economic progress has affected the mood of the country is risky. Intense political anger has also broken out during periods of strong growth, such as the 1960s. And today's economic morass cannot be blamed entirely on poor productivity growth, or even on inequality. Still, could it be that a lack of technological progress is dooming us to a troubled future, even at a time when we celebrate our newest gadgets and digital abilities—and make heroes of our leading technologists?

**How do you know?**

While Gordon's willingness to speculate about what lies ahead is one of the strengths of his book, his blanket skepticism about today's technologies often sounds unjustified, even arbitrary. He dismisses such digital advances as 3-D printing, artificial intelligence, and driverless cars as having limited potential to affect productivity. More broadly, he ignores the potential impact of recent breakthroughs in gene editing, nanotechnology, neurotechnology, and other areas.

You don't have to be a techno optimist to think that radical and potentially life-changing technologies are not a thing of the past. In "Is Innovation Over?" Tyler Cowen acknowledges the "stagnation in technological progress" but concludes there are ample reasons to be hopeful about the future. Cowen told me: "There are more people working in science than ever before, more science than ever before. In [artificial intelligence], biotechnology, and [treatments] for mental illnesses, you could see big advances. I'm not saying it is going to happen tomorrow—it may be 15 to 20 years from now. But how could you possibly know it won't happen?"

In some ways, Gordon's book is a useful counter to the popular view that we're in the midst of a technology revolution, says Daron Acemoglu, an economist at MIT. "It's a healthy debate," he says. "The techno

optimists have had too much of a run without being challenged." Yet, says Acemoglu, it's hard to accept Gordon's argument that we're seeing a slowdown in innovation:

**Whether we're doomed to a future of tough economic times will be at least partially determined by how we utilize innovation and share the benefits of technology.**

"It may well be that these innovations haven't translated into productivity. But if you look at just the technologies that have been [recently] invented and are close to being implemented over the next five to 10 years, they are amazingly rich. It is just very hard to think we're in an age of paucity of innovation." And, says Acemoglu, "to project even further into the future that we're not going to translate these innovations into productivity growth is not an easy argument to make."

One of the limitations of Gordon's book, says Acemoglu, is that it doesn't explain the origins of innovation, treating it like "manna from heaven." It is "easy to say productivity comes from innovation," says Acemoglu. "But where does innovation come from, and *how* does it affect productivity?"

Better answers to such questions could help us not only to understand how today's technical advances might boost the economy but also to make sure we implement these technologies in ways that maximize their economic benefits. Whether we're doomed to a future of dismal technological progress, and hence tough economic times, will be at least partially determined by how we utilize innovation and share the benefits of technology. Do we invest in the infrastructure that will make the most of driverless cars? Do we provide access to advanced medicine for a broad portion of the population? Do we provide new digital tools to the growing segment of the workforce with service jobs in health care and restaurants, allowing them to be more productive employees?

Gordon could be right; the great inventions of the late 1800s changed lives to an extent that will never be matched. Nor will many of the circumstances that were so conducive to economic progress during that era be seen again. But if we can better understand the potential of today's innovations—remarkable in themselves—and create the policies and investments that will allow them to be fully and fairly implemented, we will at least have a fighting chance of achieving robust economic progress again.

*David Rotman is the editor of* MIT Technology Review.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# Data-Mining Your Psyche

The latest data-driven political pitches target you based on your personality, not just your demographics. But does such profiling work?

By David Talbot

**When a state representative named** Thom Tillis ran for U.S. Senate in North Carolina in 2014, his campaign followed the now-standard practice of sending voters online and direct-mail advertisements referring to particular issues. Which issues mattered to which people, from ISIS to the Affordable Care Act, could be gleaned from the voters' memberships and donations or inferred from demographic information and databases of everything from their purchases to their Web history.

But some of Tillis's advertisements tried something new. One, which showed Tillis smiling broadly with a soft-focus background of green foliage, promised he'd "restore common sense in Washington." Another, featuring a man wearing a hard hat while poring over blueprints with his team, asserted that Tillis had "the experience to get the economy working." A third showed the camouflage-smeared face of a soldier and contained this promise from Tillis: "Your safety is his top priority."

Which version went to whom depended on how the Tillis campaign assessed the recipient's *personality*. The grinning picture? That went to people who tended to be "agreeable." Hard hat? That one was aimed at people deemed "conscientious." Soldier? That one was reserved for people thought "neurotic."

The Tillis campaign made the ads with help from Cambridge Analytica—an offshoot of a British firm called SCL Group, which has long been involved in campaigns (commercial, political, military) that leverage behavioral-science

SOPHIA FOSTER-DIMINO

research. Like other big-data analysis companies, it categorizes voters on the basis of demographics and issues, but it appears to be the first to add personality typing to the mix. The company says it has assessed the personalities of all 190 million registered voters in the United States. "We can now start to really look at people based on their psychographics, not just their demographics," says Alex Tayler, chief data officer at Cambridge Analytica's headquarters in London.

**Behavioral Microtargeting System**
Cambridge Analytica, Alexandria, Virginia

It's a fairly new approach, and no published data shows that what Cambridge Analytica is doing adds any real value. "Many basic categories of data tend to be very predictive in terms of voting habits: voting history, party registration, age, gender, race, marital status, presence of children, and some basic census measures," says Daniel Kreiss, a professor of political communication at the University of North Carolina, Chapel Hill. "Everything else gives you only marginal potential advantages. Is personality the strongest predictor of whether someone is persuadable versus any of these other things? I haven't seen any data that has suggested that this form of modeling does or doesn't work."

In fact, there are large gaps in our understanding about many kinds of data-driven campaigning, says Gregory Huber, a political scientist at Yale. In 2012, President Obama's campaign operatives analyzed data about individual voters' issue preferences and demographics to craft messages tailored to them (see "A More Perfect Union," January/February 2013). Obama won reëlection, but did the microtargeted persuasion efforts have anything to do with it? "There is almost nothing known about whether that stuff worked or not," says Huber. "There are books written that are descriptive exercises of what the campaign was doing. But in terms of a valid, unbiased, randomized assessment of its effectiveness, I don't think we know much at all."

**Are you someone who worries? Has a vivid imagination? Trusts others?**

Nonetheless, academic research has established a relationship between personality and political leanings—and has found that some types of personalities are more persuadable than others. Such basic research doesn't necessarily translate into a practical campaign strategy, but it does suggest that personality typing might provide something that demographics alone can't. And it is tantalizing enough to persuade some campaigns to give Cambridge Analytica's tools a try. The company, which represents Republican and conservative candidates, worked on 44 state and federal races in the United States in 2014. This year it has worked for the presidential campaign of Ted Cruz, the U.S. senator from Texas.

**Are you agreeable?**

Cambridge Analytica's technology attempts to define a voter's predominant personality type—adding this to the list of things campaigns know about you. But while the microtargeting is new, the basic concepts about personality are old. In the past three decades, disparate research groups have identified a set of basic personality traits. Often called the "Big Five," they can be summarized by the acronym "OCEAN": openness, conscientiousness, extroversion, agreeableness, and neuroticism. Classification is typically done through questionnaires. Among the typical questions: Are you someone who worries about things? Makes friends easily? Has a vivid imagination? Trusts others? Completes tasks successfully? And so on.

**The "Big Five" Traits**
If you rank high in ...

**Openness**
You are intellectually curious and tend to think and act in individualistic and nonconforming ways.

**Conscientiousness**
You set clear goals and are reliable, organized, and self-controlled.

**Extroversion**
You enjoy being with other people, are full of energy, and tend to seek out opportunities for excitement.

**Agreeableness**
You value getting along with others and believe people are basically honest, decent, and trustworthy.

**Neuroticism**
You tend to experience negative feelings and to interpret ordinary situations as threatening.

Here's how the company does it: Cambridge Analytica administers such questionnaires online, promoting them using ads that promise to tell you the relative weight of your personality traits. The company says it has used these tests to "harvest" the personalities of several hundred thousand Americans. Even if you haven't taken one of its tests, the company categorizes you by extrapolating. It concludes that you tend to be, say, agreeable or neurotic by matching statistical profiles made up of as many as 5,000 commercially or publicly available data points about you to the statistical profiles of people who *actually* took the personality tests and came out as agreeable or neurotic and so on. (It will not discuss the particulars of these statistical matches but says the data come from consumer database companies

including Acxiom, Experian, Infogroup, and Aristotle, as well as the Republican Party's voter file.)

By this means, Cambridge Analytica claims to have acquired a rough sense of the personalities of much of the U.S. population. Assuming the method is accurate, your personality type then provides an extra layer of information about you, atop the demographics and other information campaigns and their consultants already use. The result could be an ad geared toward your agreeable personality, even if you are demographically quite similar to the neurotic guy next door.

**Your personality type provides an extra layer of information about you, atop the demographics campaigns already use.**

When this information is shared with political candidates, their campaigns can devise and test ads in small groups to see which ones are effective. To serve individual ads online, Cambridge Analytica uses the standard marketing practice of matching its data to cookies—small pieces of data that track your computer's visits to websites—using third-party services like Acxiom that merge online and offline data about you. In addition, Facebook serves as a major platform for targeted ads. While Facebook says it does not provide data that could reveal your personality, it will display customized ads to lists of individuals provided by a political campaign. Finally, not all of the targeted messaging occurs online; some campaigns mail customized ads to voters' homes.

**Too much information**

A large and growing body of research shows that personality traits predict a wide array of behaviors, financial decisions, and happiness levels in jobs and relationships. When it comes to politics, research at the University of Toronto and the University of Minnesota has found that people with "openness" as a major trait tend to favor liberal candidates, while people who scored relatively high on "conscientiousness" tend to be more conservative.

Your personality also probably plays at least some role in your overall susceptibility to persuasion—a valuable thing for a political campaign to know. Several years ago a group of political scientists at Yale University and other institutions found that social pressure could encourage people to vote. If voters were presented with information detailing which of their neighbors had voted—and were told that their own record of showing up at the polls might be similarly publicized—they were far more likely to go


*The ad voters received from Thom Tillis's 2014 Senate campaign in North Carolina depended on whether the campaign thought the recipient was conscientious, neurotic, or agreeable.*

COURTESY OF CAMBRIDGE ANALYTICA

to the polls. (The fact that you voted—but not for whom you voted—is public information.) People who scored high on "emotional stability" and "openness" responded more strongly to this social pressure.

So if you wanted to devise a campaign that used social pressure to get your supporters out to vote but had finite resources to do it, it would make sense to focus on reaching people you suspected had personalities characterized by emotional stability and openness, says Huber, who cowrote the study.

At the same time, there's reason to wonder if we've reached the limit of what data analytics can actually achieve by microtargeting individual voters. Campaigns have plenty of methods to experiment with: as of 2012, by Kreiss's count, technology and data-science staffers on presidential campaigns had founded 67 companies to work for Democrats and another 13 for Republicans. But the campaigns may be getting overconfident in what algorithms can really do.

"The problem with data analytics and all these models is that they all look backwards, not forward," says Micah Sifry, cofounder of Personal Democracy Media, which produces the annual Personal Democracy Forum conference on how technology is changing politics. "The best thing they can do is offer you a prediction on what people are likely to do based on what they did in response to stimuli in the past."

In this election year, filled with fast-changing trends and unpredictable candidates, that dependence on past behaviors and basic personality types could be an unreliable way to gauge a person's political preferences. Maybe we need to add another distinguishing trait to match with voters: anger.

*David Talbot is senior writer at* MIT Technology Review.

# Demo

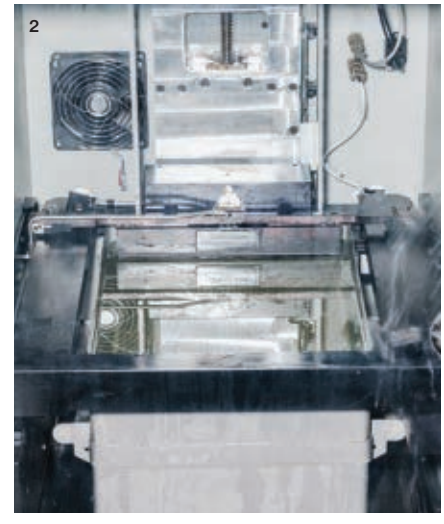
Chemical engineer Zak Eckel and group leader Tobias Schaedler

# 3-D-Printed Ceramics

A new way of making these tough materials could be a key step in producing better airplane engines and long-lasting machine parts.

By Katherine Bourzac
Photographs by Julian Berman

1



2

**Ceramics are some of the hardest materials** on Earth. They can withstand extreme temperatures, and some are impervious to friction, scratching, and other mechanical stresses that wear out metal and plastic. But it can be difficult to make complex shapes out of the materials.

Chemists at HRL Laboratories in Malibu, California, may have gotten around that problem by developing ceramics that can be made in a 3-D printer. The result: ultrastrong objects that are impossible to make using conventional methods.

Ceramics are used today in brake pads, the housing of microelectronics, and thermal shielding tiles (like the ones on spacecraft). Now the scientists at HRL are trying to substantially expand the applications. If parts for aircraft engines were made of ceramic, for example, the engines could run at a higher temperature, increasing their efficiency.

**1** This beaker of resin contains polymer precursors that can be run through a 3-D printer to make objects.

**2** In the printer, ultraviolet light strikes the resin, hardening it to build things one layer at a time.

**3** After about 90 minutes of printing, this small part, an impeller, emerges from the resin bath. Impellers are used in steam turbines and other machinery that must weather wear and high temperatures.

3

**4** The printed part is treated in a furnace to bake the polymer and turn it into a ceramic. In the process, the part shrinks by about 30 percent.

**5** Schaedler gets ready to pull the ceramic part out of the 1,000 °C furnace.


**6** To test the material's heat tolerance, HRL scientists put it under a torch of about 1,200 °C.

**7** In addition to printing individual parts, the process can yield lattices like this one, which can be flexed and twisted to make more complex shapes or to fit a surface such as an airplane wing.

**8** Larger pieces of printed ceramic mesh and lattice sheets like these could be used to shield spacecraft from extreme temperatures.





Ceramics could also offer an upgrade on parts used in steam turbines and other machines that must withstand searing, mechanically harsh conditions. The lab is co-owned by Boeing and General Motors, and the project has some funding from DARPA, the R&D arm of the U.S. Department of Defense.

HRL's trick is to formulate special resins that can be used as the ink in a printer. They are made out of polymers but carry in their molecular structure silicon and other elements found in ceramics. These resins are loaded into 3-D printers to make parts with baroque shapes, such as corkscrews and sheets of intricate lattices. Then those parts go into a furnace to bake out the organic polymer components, leaving behind ceramic material.

The 3-D-printed ceramics could be better in some respects than their conventional counterparts. One lattice made at HRL has 10 times the compressive strength of commercially available ceramics. These printed parts can also tolerate heats as high as 1,700 °C, a temperature at which other ceramics start to degrade.

But the group still hopes to make its printed ceramics stronger. One approach is to design new kinds of pre-ceramic polymers that have fibers embedded in them to stop cracks from spreading. Ceramics are brittle and can fail catastrophically with one crack. It wouldn't do if a minuscule defect caused a clever new part to shatter.

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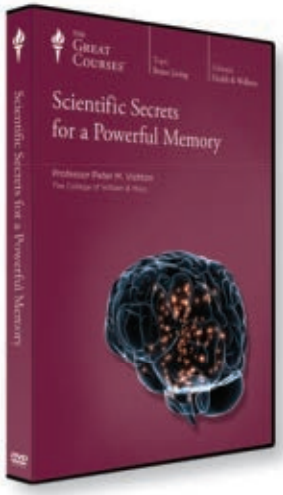


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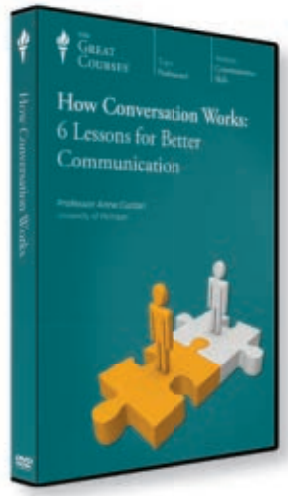


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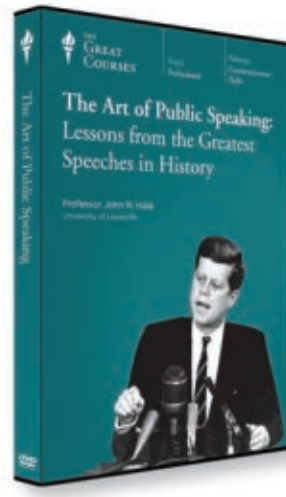


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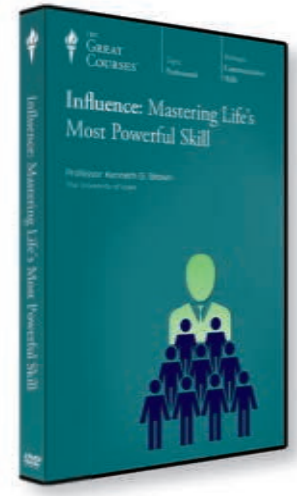


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# 24 Years Ago


## Do We Deserve Total Digital Privacy?

A quarter-century ago, a "protracted battle" over encryption began between law enforcement and civil-rights activists.

"Digital technology offers, in principle, unprecedented privacy. It is possible to use a computer program to encode a message so that its meaning will be revealed only to someone possessing a digital key. Such 'encryption' serves two principal purposes: it ensures that only the person for whom the message is intended will read it, and it guarantees that the person who appears to have sent a message is indeed the actual sender. Without encryption, someone skilled in software manipulation can with relative ease impersonate someone else over the network. (Although virtually all systems require users to enter a password, hackers can run programs that quickly try dozens of likely passwords.)

Meanwhile, the law-enforcement community, seeing computer networks as the latest venue for criminals to conspire, may soon attempt to restrict domestic encryption directly. The proposal reflects the FBI's concern that the new digital network will stymie attempts to conduct court-sanctioned surveillance. Old-fashioned telephone lines can be tapped with relative ease, says James K. Kallstrom, the FBI's chief of investigative technology, since each voice conversation travels along its own wire loop. Although Kallstrom says that members of the law-enforcement community 'only want to keep the same access we already have,' the FBI's proposal has raised a fury among civil libertarians. 'Wiretapping is a necessary evil, but to treat it as an entitlement would be a great mistake,' says Marc Rotenberg, director of Computer Professionals for Social Responsibility's Washington office. Alan Westin, professor of public law and government at Columbia University, concurs: 'It's like saying that no private home may have thick steel doors because some day the police might want to kick the door in as part of a lawful criminal investigation.'

The FBI proposal marks an opening salvo in what could become a protracted battle between government agencies and civil-liberties advocates. But even those allied with the law-enforcement community admit that public demand will eventually bring encryption into widespread use, says Donn Parker of SRI International in Menlo Park, California. The question then becomes how to catch the bad guys without tapping their phone calls."

*Excerpted from "Of Bytes and Rights," by senior editor Herb Brody, in the November/December 1992 issue of* Technology Review.

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